WHITE PAPER

The Energy Cloud

Emerging Opportunities on the Decentralized Grid

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Section 1
EXECUTIVE SUMMARY

1.1 Emerging Energy Cloud

The power sector is undergoing a fundamental transformation, shifting from a centralized hub-and-spoke grid architecture based on large centralized generation assets like fossil fuel, hydro, or nuclear power plants toward an increasingly decentralized electrical grid that makes use of distributed energy resources (DER). The growth of DER is being accelerated by broad discussions and evolving regulation on carbon emissions, a more proactive consumer or prosumer, and increased financial viability compared to traditional generation because of continuous lower price points to produce and install DER. This shift away from traditional power plants encompasses a diverse suite of technologies that go beyond DER. Energy storage, energy efficiency, demand response (DR), and the advanced software and hardware that enable greater control and interoperability across heterogeneous grid elements are all key components of the emerging energy cloud.

Organized to help manage supply and demand across the grid, the energy cloud shares many characteristics with cloud computing. As with the IT cloud, these dynamic networks can enhance the efficient allocation of DER—including solar, wind, and energy storage systems—across a broad customer base. Greater stakeholder collaboration and maximizing the potential of decentralized power generation are among the energy cloud's important benefits as efforts to modernize an aging grid continues to gain momentum.

Four key trends underpin the evolution toward the energy cloud:

» Increased broad discussion, development, and implementation of new regulations to reduce carbon emissions (e.g., Environmental Protection Agency [EPA] 111d and European Union [EU] Carbon Emissions ruling).

» The transition toward an increasingly decentralized grid architecture as a result of a dramatic rise in DER.

» Greater customer choice—more clients want control over their electricity usage and spend, as well as when and what type of power they buy or, in more extreme cases, the ability to self-generate and sell onsite power back to the grid.

» Increasing availability of data related to the edge of the electrical grid, enabled by healthy growth in smart grid infrastructure.

The end result of this transformation shift is a reimagining of how we generate, store, and consume energy in the next 20 years. More specifically, the energy cloud represents a transition from one-way power flow to a dynamic network of networks supporting two-way energy flows at the periphery of the grid.

This paper offers a perspective on the emerging energy cloud, describing its basic elements and examining its likely impact on the power utility sector. The growth in the deployment of key technologies like distributed solar PV, energy storage, and virtual power plants (VPPs) is profiled in order to demonstrate both the velocity and scale of an evolutionary shift toward the energy cloud. A discussion around how this paradigm shift will affect the traditional utility-consumer relationship offers insight into challenges facing utilities as their customers embrace distributed generation (DG) and opportunities provided by new entrants to engage more proactively in the market. Finally, this paper explores the emerging strategies that utilities are taking to both embrace change and thrive in this evolving environment.

Section 2
DEFINING THE ENERGY CLOUD

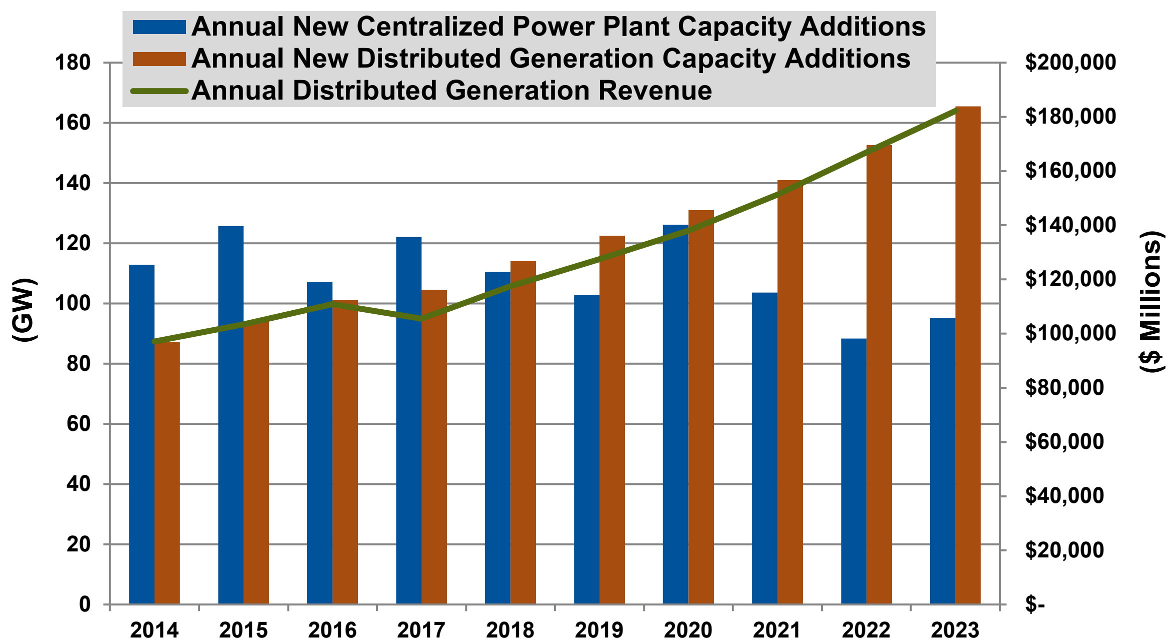
2.1 The Energy Cloud

The energy cloud is both the result of a fundamental shift in the way electricity is generated and distributed as well as an evolution of the traditional relationship among stakeholders across the electrical grid, particularly between utilities and their customers. As a concept, the energy cloud represents a wide range of strategic, operational, technological, commercial, environmental, and regulatory changes that are transforming the traditional utility model for energy provision. More practically, the energy cloud is an emerging platform on which advanced technologies and solutions may be integrated and compete for market share in a dynamic marketplace.

Four key trends underpin the evolution toward the energy cloud. First, regulations that tighten restrictions on carbon emissions are accelerating a shift toward renewables and efficiency and away from fossil-based centralized generation. In June 2014, as the centerpiece of President Obama's Climate Action Plan, the Environmental Protection Agency (EPA) released the Clean Power Plan, a proposal to regulate CO_2 emissions from existing fossil fuel power plants under section 111(d) of the Clean Air Act. Compliance options that are expected to be included in state implementation plans include energy efficiency programs and low or zero carbon generation, including distributed renewables. The regulation is certain to face litigation after it is finalized. However, many states and utilities are moving forward with low carbon plans that include both energy efficiency and distributed renewables despite the uncertainty surrounding the final regulation. Across the Atlantic, the European Union (EU) is on track to meet its target of reducing greenhouse gas emissions by 20% compared to 1990 levels by 2020. This target has driven a variety of policy actions taken by European countries to reduce emissions, many of which have spurred an increasing penetration of energy efficiency and distributed renewables, particularly distributed PV.

Second, fueled in part by the rapidly declining cost of distributed energy resources (DER) technologies like solar PV and energy storage, a rapid increase in the deployment of DER is driving a shift toward distributed generation (DG). Navigant Research estimates that between 2014 and 2023, DG will displace the need for more than 320 GW of new large-scale power plants globally.[1] Navigant Research's *Global Distributed Generation Deployment Forecast* report estimates that new DG capacity additions will exceed new centralized generation capacity additions by as early as 2018.

Chart 2.1 Annual Centralized Power Plant and DG Capacity Additions and Vendor Revenue, World Markets: 2014-2023



(Source: Navigant Research)

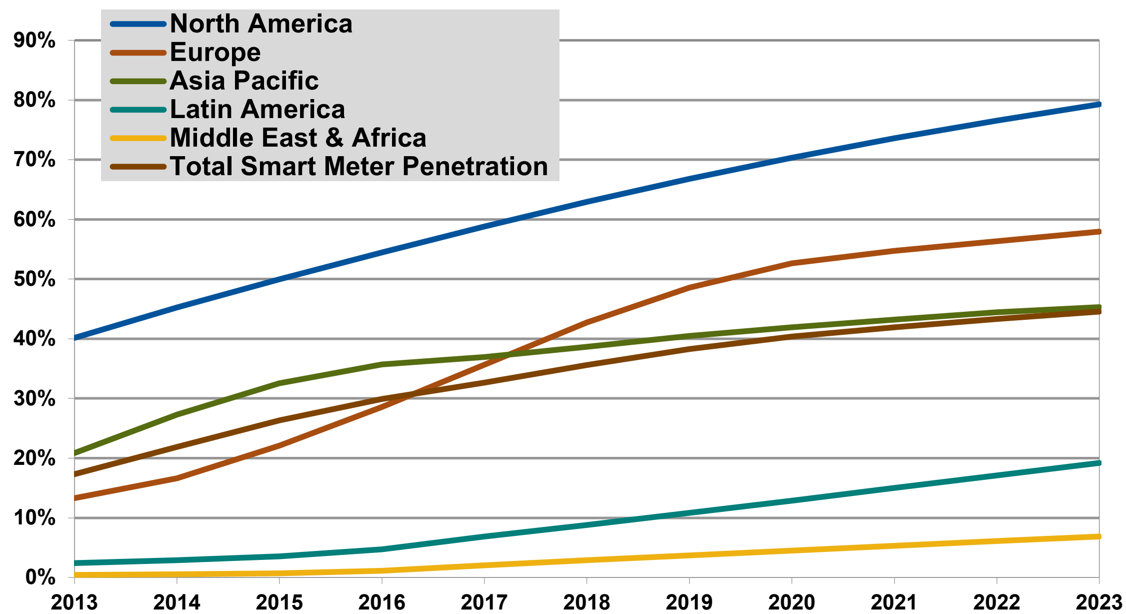
Third, evolving energy consumer demands and enablement of customer choice are also accelerating a shift toward the energy cloud. Customers are increasingly focused on engaging in both the purchase and sale of energy, and if appropriately incentivized, can provide other services such as balancing, voltage support, and voluntary load management that address broad industry goals of greater efficiency and resilience. Efforts to transition the distribution grid away from a commodity business to one focused on service through improved rate design, liberalization of net metering rules, and other initiatives will drive greater innovation across the electrical grid.[2]

[1] *Global Distributed Generation Deployment Forecast,* Navigant Research, 3Q 2014.

[2] Edison Electric Institute/Natural Resources Defense Council (EEI/NRDC) Joint Statement to State Utility Regulators, February 2014.

Fourth, smart grid infrastructure is beginning to reach a threshold sufficient to drive increasing digitalization of the electrical grid. A significant rise in spending by utilities to replace and upgrade infrastructure supports this long-term growth trend. Increased grid automation and demand response (DR) spending across the advanced energy economy, for example, reached a combined $70 billion in annual revenue globally in 2014, according to Navigant Research estimates.[3] Advanced distribution management systems (ADMSs), for example, have seen an explosion in investment as utilities increasingly grapple with complex challenges associated with integrating smart grid IT/operations technology (OT) deployments. Navigant Research's *Smart Meters* report, for instance, estimates that smart meter penetration has approached 50% in North America and is expected to reach 70% by 2020.[4] Similar saturation trajectories are observed in Europe and Asia Pacific, as well.

Chart 2.2 Smart Meter Penetration Rate of All Electric Meters by Region, World Markets: 2013-2023



(Source: Navigant Research)

[3] *Advanced Energy Now 2015 Market Report: Global and U.S. Markets by Revenue 2011-2014 and Key Trends in Advanced Energy Growth*, AEE (prepared by Navigant Research), March 2015.
[4] *Smart Meters*, Navigant Research, 3Q 2014.

The emergence of the energy cloud—and the underlying trends and technologies that are enabling its operation—provide an early peek into a broader paradigm shift in the electric utility industry. Not unlike disruptive challenges that led to dynamic change in the telecom industry, for example, the energy cloud requires incumbent players to be considerably more flexible than today's business models allow in order to both accommodate the degree of technological change transforming the grid and thrive in an increasingly competitive marketplace. Ultimately, the emerging energy cloud will be far more dynamic, responsive, and democratized than what current infrastructure can support.

2.1.1 Cloud Computing and the Energy Cloud

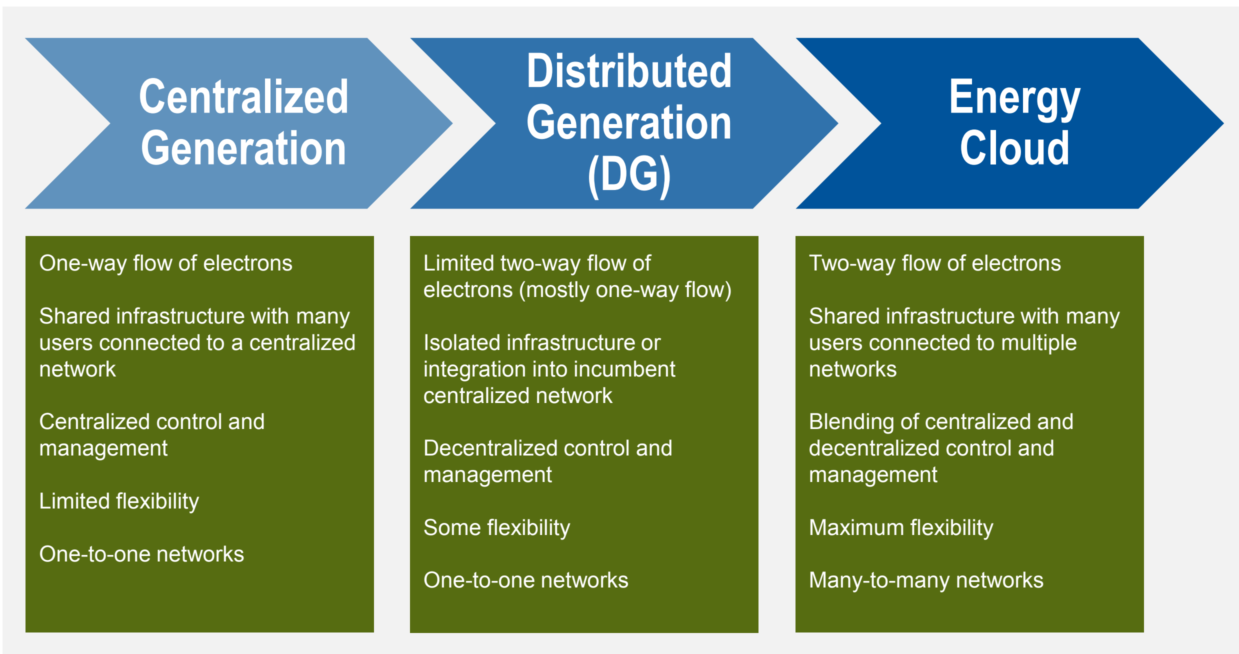
The energy cloud concept has its genesis in cloud computing, which, in the IT world, represents the game-changing move from the localized provision of IT power (i.e., on the desktop, in a department or division, or in a single enterprise) to the use of centralized networked services that have the flexibility and capacity to meet growing requirements for IT services in an on-demand and cost-efficient manner. These networks blend both the economic efficiency of having centralized operations while coordinating services across a large pool of connected end users.

The history of cloud computing dates back to the 1950s, when the colossal hardware associated with mainframe computers required installation in dedicated server rooms with users accessing these machines via standalone terminals through mostly one-way commands. Due to the cost of buying and maintaining mainframe computers, multiple users were given shared access to a single mainframe, effectively operating as a network of end users accessing a centralized installation. Computing architecture at this stage of development closely resembled the architecture of the incumbent electrical grid, with multiple customers connected to centralized generation assets via a transmission and distribution (T&D) network that enables a one-way flow of energy.

Eventually, a centralized, shared client server accommodated multiple end users running software on their own machines with varying degrees of coordination. This model closely resembles the current electrical grid, in which DG is adopted across the periphery of the distribution network, but without a high level of coordination and sophisticated control taking full advantage of these resources across the network.

Over time, the rapid growth of the Internet and the desire for consumers to get online coincided with significant breakthroughs that enabled the cloud computing model we see today to fully materialize. Similarly, as described in Figure 2.1, the energy cloud represents the shift away from a centralized energy generation and distribution architecture—consisting primarily of large, fossil fuel, nuclear, and hydro generation plants connected to customers by extensive T&D infrastructure—toward a networked and dynamic infrastructure that integrates demand-side generation technologies and capabilities as well as distributed renewable energy resources alongside traditional assets.

Figure 2.1 The Energy Cloud Evolution from Centralized and Distributed Generation



(Source: Navigant Consulting)

Similar to cloud computing, the energy cloud blends the best of prior models—including the economies of scale offered by centralized generation with the flexibility and resilience offered by networks of DER. This non-linear ecosystem involves multiple inputs and users relying on a high degree of digitalization to support two-way energy flows. Such a system is characterized by increased complexity and redundancy, allowing for greater choice in the manner in which energy is generated, supplied, and consumed. Replicating the emergence of many-to-many networks of users (e.g., social media), the energy cloud leverages highly coordinated energy networks across the grid, incorporating both traditional interactions (e.g., utilities and their customers) and emerging interactions (e.g., consumer-to-consumer, consumer-to-service provider, etc.).

The energy cloud paradigm is closely related to the Internet of Energy (IoE), but the two concepts are not interchangeable. The IoE describes the interconnection of multiple devices, and more specifically, the shift from centralized generation to a distributed and shareable power grid. While the energy cloud is enabled by this broad trend as described earlier, it also includes the platform on which energy marketers, service providers, and consumers will engage to facilitate greater coordination and sophistication in the way in which energy is exchanged.

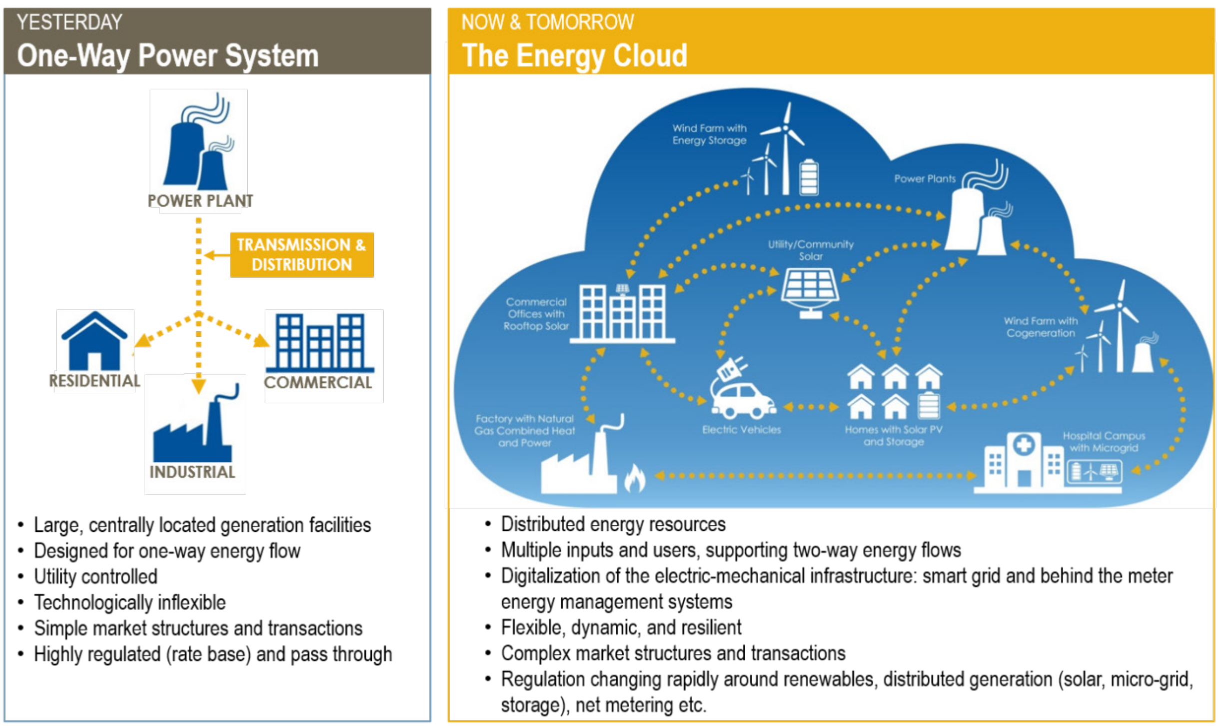
2.1.2 Visualizing the Energy Cloud

The energy cloud architecture is not only vastly different from the conventional architecture of the traditional hub-and-spoke model represented by the incumbent electrical grid, but is also much more sophisticated in its operating characteristics and capabilities.

The current electricity system—operating primarily to manage supply and demand across the network—has been called the most complex machine developed by humans. Safe and reliable service is a function of many interdependent components working in coordination to deliver consistent power around the clock. The bulk of this management takes place along the macro-grid and is focused on one-way power flows, as shown in Figure 2.2. Outages across the heart of the grid lead to catastrophic blackouts, and grid operators go to great lengths to avoid such events. Downed power lines across the distribution grid, while equally disruptive for those without power, are an accepted reality with few tools deployed today to improve resilience. Customers in this outdated model have few options to insulate themselves from catastrophic events causing disruptions to service.

The grid of the future, which will provide the backbone of the energy cloud depicted in Figure 2.2, aims to integrate DER more fully into the distribution grid. This architecture will enable a two-way power flow such that distinctions between distribution and transmission grids will blur. The acceleration in the sophistication and pervasiveness of remote monitoring and automation equipment, combined with robust data analytics, for example, is allowing more granular and real-time control over generation and consumption at the edges of the grid. This mix of hardware and software enables greater precision with respect to matching localized supply and demand with higher levels of frequency. Perhaps more importantly, this functionality hardens the grid against external events and allows for greater coordination with human intervention. Offered via the energy cloud, these capabilities may be delivered as services by utilities and third-party vendors alike.

Figure 2.2 The Energy Cloud: Yesterday, Today, and Tomorrow



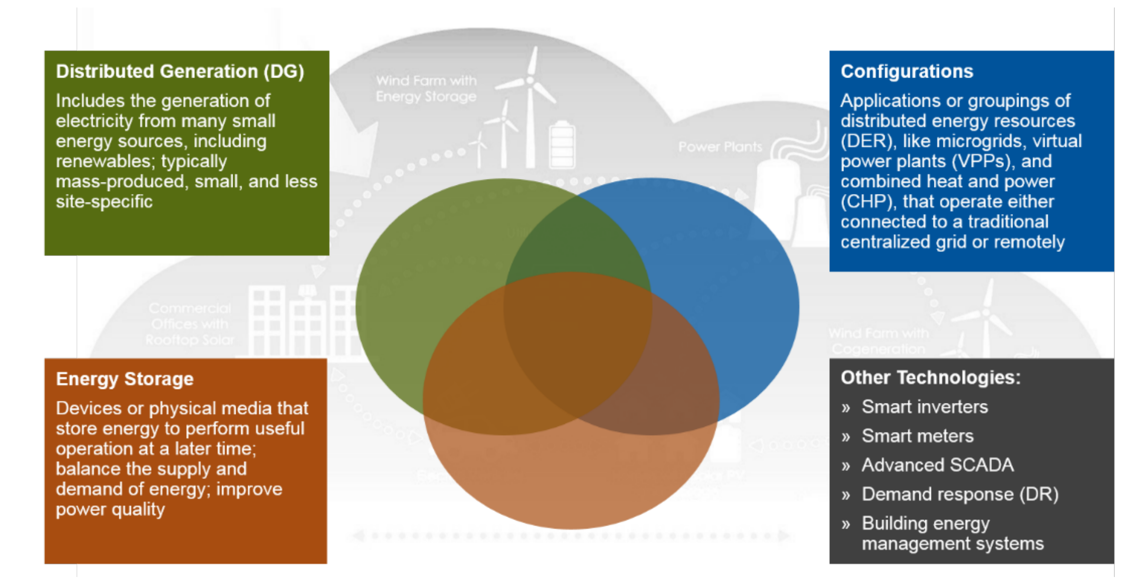
(Source: Navigant Consulting)

As the grid evolves toward this interconnected state, the energy cloud will need to accommodate many new layers of functionality in order to unlock the benefits of an increasingly dynamic and open architecture. With emerging technologies and services patched into the existing system in real-time, assumptions related to traditional supply and demand forecasts will become obsolete. The emerging energy cloud will also need to remain flexible in order to integrate rapid innovation across many interrelated technology verticals. Utilities and grid operators will need to become more holistic in their planning to anticipate the complex interdependencies these solutions will create.

2.2 Energy Cloud Enabling Technologies

The energy cloud sits at the confluence of broad technology trends influencing the power generation, grid infrastructure, built environment, and transportation environments. Renewable and fossil fuel DG, energy storage, and technology configurations such as microgrids and virtual power plants (VPPs) are the workhorses within the energy cloud landscape. Yet, embedded hardware (such as smart meters and smart inverters interconnected through advanced supervisory control and data acquisition [SCADA] and ADMS capabilities) and software form the glue that binds the energy cloud together (see Figure 2.3) and enables its operability. Greater penetration of these hardware and software solutions leads to enhanced DR opportunities and more robust energy efficiency capabilities, such as advanced building energy management systems (BEMSs).

Figure 2.3 The Energy Cloud Technology Landscape



(Source: Navigant Consulting)

Drawing from examples spanning Navigant Research's Energy Technologies, Utility Transformations, Building Innovations, and Transportation Efficiencies research programs, this white paper explores two key questions as they relate to the energy cloud across four technology categories:

- **What is the scale of the opportunity?** How transformational will the impact of the technology be on the traditional grid? What is the scale of the investment opportunity?
- **What is the velocity of change?** What is the rate of change in which the energy cloud will evolve? When will key technologies reach a level of critical penetration?

The four technology categories profiled below include:

- Solar PV
- Energy storage
- BEMSs
- VPPs

Representing just a small piece of the energy cloud landscape, these technologies, along with the services they enable, demonstrate that the scale of the investment opportunity in the energy cloud is substantial and the rate of change or evolution is occurring rapidly. Each is deployed at scale today. Viewed together, they represent nearly $1 trillion in potential cumulative investment over the next decade.

2.2.1 DG: Solar Leads the Way

Navigant Research's *Global Distributed Generation Forecast* report, which analyzes the growth of DG across 54 individual countries in seven geographic regions, anticipates that 1.1 TW of cumulative DG capacity—including solar PV, small wind, fuel cells, microturbines, and generator sets (gensets)—will be installed between 2014 and 2023. This represents roughly one-third of the anticipated total generation capacity added worldwide over the same period. In 2014, nearly half of the added generation capacity globally was classified as DG. Lower-cost points for emerging technology, greater incentivization through net metering and feed-in tariff programs, and evolving customer demand for self-generation and greater choice are among the many drivers for increasing levels of DG penetration like solar PV. These forces are transitioning the electric power system to become more flexible, cost-effective, and resilient, with the energy cloud enabling these attributes.

While diesel- and natural gas-fueled gensets are well-established, emerging technologies are expanding the suite of technology options on the grid. The remarkable rise in solar PV capacity is spearheading this growth. Rapid module price drops combined with the proliferation of leasing programs and other innovative financing options have helped solar PV reach grid parity despite governments reining in financial incentives. According to Navigant Research estimates, solar PV capacity deployments between 2014 and 2023 will represent one-quarter of all the DG capacity installed and generate more than $700 billion in cumulative vendor revenue.[5] Other emerging DG technologies, such as microturbines and fuel cells, are beginning to gain traction in solar PV's wake.

Although DG provides many benefits to the grid, it also poses complex challenges for grid operators. The intermittency of solar PV and small wind, for example, make it especially difficult to manage rapid ramping.

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[5] *Global Distributed Generation Deployment Forecast*, Navigant Research, 3Q 2014.

A solar eclipse that took place in Europe during March 2015 demonstrates the significance of high levels of solar penetration on the grid and the need for more sophisticated energy cloud infrastructure to manage supply and demand at the distribution level. According to several news outlets:

- In Germany, solar output dropped from 21.7 GW at the start of the eclipse to 6.2 MW at its minimum, and then rose back up to roughly 21 GW throughout the rest of the eclipse.
- The ramp-down and ramp-up rates (such as MW/minute) due to solar power and the eclipse were 2.7 times and 3.5 times faster than the normal duck curve that Germany experiences.
- At one point, 4,400 MW was added to the grid in 15 minutes in Germany (293.33 MW/minute, or a nuclear power plant every 5 minutes).
- Coping mechanisms for the ramp-down included using hydroelectric electricity and quick-start natural gas plants, as well as DR solutions.
- Italy shut off a number of solar systems as a way of coping with the sudden drop in solar production in order to reduce balancing issues.

Complicating efforts to accommodate such events are the varied capabilities and attributes of individual DG technologies. While no one-size-fits-all solution exists with respect to interconnecting these resources to the grid, increased penetration of DG technologies is forcing a market shift toward the energy cloud. By providing a platform for integration and remote operability, the energy cloud will play an instrumental role in balancing DG output with demand in real-time. These capabilities will allow DG to fill in the gaps in an aging grid and, where appropriate, incorporate redundancy into the system to harden the grid against unpredictable disruptive threats.

2.2.2 Energy Storage: The Linchpin Resource

From well-established solutions like pumped storage hydro and flywheels to emerging technologies, such as advanced battery chemistries and vehicle-to-grid, energy storage is emerging as a linchpin solution in the energy cloud market, helping to shift electrons across time and allowing for more flexibility in balancing demand and supply loads. The pace with which the energy storage market evolves will have a profound impact on the pace with which the energy cloud matures.

Utilities and grid operators (regional transmission organizations/independent system operators, or ISOs) grappling with the challenges posed by increased DG adoption on the grid are currently benefitting from a parallel expansion in the availability of energy storage technologies. These solutions can provide significant utility-scale load-leveling and frequency regulation capabilities, as well as behind-the-meter storage capabilities for consumers. Paired with intermittent renewables, energy storage becomes one option to provide reliable energy supplies.

Navigant Research's *Energy Storage for the Grid and Ancillary Services* report forecasts that revenue for energy storage technologies in various load-balancing applications—grid asset optimization, utility-scale wind integration, utility-scale solar integration, arbitrage, T&D upgrade deferral, frequency regulation, voltage support, spinning reserve/electric supply reserve capacity, load following, and grid-tied community storage—is expected to exceed $6 billion by 2020, representing more than a sixfold increase over 2013 annual vendor revenue. California utilities have been ordered by the California Public Utilities Commission (CPUC) to procure 1,325 MW of energy storage by 2020. Meanwhile, behind-the-meter energy storage applications are also on the rise. Approximately 26,000 residential energy storage systems were sold globally in 2013. This segment is expected to see a 25-fold increase in system sales by 2020.[6]

Beyond enabling the shifting of electrons across time, energy storage will also have a profound impact on future grid infrastructure by allowing for the shift of electrons across space and beyond the traditional grid in the form of electric vehicle (EV) batteries. Just as mobile gensets can be deployed in real-time to provide electricity generation capabilities to off-grid applications or to communities affected by blackouts, adding a degree of flexibility to electricity generation and consumption, vehicle-to-grid technologies allow electrons to be moved from one location on the grid and connected to another without the use of traditional wires. Fleetwide management of EVs expands the energy cloud's benefits by not only providing greater coordination in the management of electrons across traditional infrastructure (i.e., poles and wires), but also enabling the ability to aggregate and deploy electrons in parallel with the physical grid.

2.2.3 BEMSs: Empowering the Consumer

BEMSs are the data-driven decision support tools that define the next generation in facilities and operations management. They enable the strategic management of operations and maintenance, investment in building system upgrades, and the utilization of energy and DR within a facility or across a portfolio. BEMS solutions that enable optimization (e.g., across facilities within a campus) or aggregation across a portfolio turn buildings into resources that can be integrated into and managed in the energy cloud. These solutions are deployed at scale today and, due to their high variability and dependence on human interaction, will require a high degree of coordination across the energy cloud to maximize their benefit as a networked energy resource.

BEMS is an encompassing term for technology and service offerings that deliver business improvements through energy and operational efficiency. Navigant Research defines BEMSs as IT-based solutions that extend the capabilities of sensing, control, and automation hardware to direct both automated and manual improvements to system operations. BEMS offerings deliver efficiency in one of two ways: via focused improvements in heating, ventilation, and air conditioning systems, lighting, plug loads, or fire and security systems, or through the

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[6] *Community, Residential, and Commercial Energy Storage*, Navigant Research, 4Q 2014.

integrated management of multiple systems. A well-designed and well-implemented BEMS provides energy, cost, and maintenance savings while supporting strategic corporate objectives, such as sustainability and climate-related goals. BEMSs can change the energy management paradigm to deliver strategic and holistic management of facilities and equipment. According to Navigant Research, BEMS vendor revenue is expected to reach $2.4 billion in 2015 and grow to $10.8 billion by 2024 at compound annual growth rate (CAGR) of 18.2%.[7]

The BEMS market continues to evolve, and the most advanced solutions are deployed among progressive early adopters. Nonetheless, BEMSs represent an important enabler of the energy cloud. Navigant Research's analysis suggests that enterprise building owners and corporate executives increasingly recognize energy as a critical business financial metric. As the market matures, BEMSs will become widespread tools for business intelligence and strategic energy management. Early use cases in the market illustrate that the development of facilities with mature BEMSs and the expansion of the energy cloud are mutually beneficial. Smart grid infrastructure combined with the energy cloud enables the automated optimization of a mature and interconnected BEMSs infrastructure. At the same time, a facility or enterprise that employs a sophisticated BEMS can become responsive to the smart grid with automated peak shaving, shifting, or ongoing operational response to grid signals, as well as the dynamic deployment of onsite DER.

2.2.4 VPPs: The Ultimate Energy Cloud?

VPPs—not necessarily a discrete technology in and of itself, but a cluster of DER including distributed solar PV, wind turbines, backup gensets, micro combined heat and power, and DR collectively managed by a central control entity—represent an early model of the energy cloud in operation. Matching load fluctuations through forecasting, advance metering, and computerized control, while also performing real-time optimization of energy resources, VPPs go beyond an IoE framework by providing sophisticated supply and demand balancing on the grid. The primary differences between VPPs and the energy cloud are scale and application.

VPPs are designed more or less to maximize asset owners' profits, delivering benefits primarily to the entity that controls it. The VPP business model, however, is quickly gaining traction in utility markets as a tool for integrating greater renewable capacity on the grid. Enabling power providers to take advantage of economies of scale through aggregation and optimization, VPPs maximize the value of electrons flowing across the system. According to Navigant Research, the VPP market is expected to grow from $1.1 billion in annual vendor revenue in 2013 to $3.6 billion per year by 2020.[8]

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[7] *Building Energy Management Systems*, Navigant Research, 1Q 2015.
[8] *Virtual Power Plants*, Navigant Research, 2Q 2014.

Key to the value of VPPs is their ability to deliver supply and demand flexibility, which will be increasingly necessary to accommodate fast ramping periods and address corresponding supply forecast errors. The brain of the VPP is a sophisticated energy management system based on robust data models that bridge energy resources on the one hand and energy markets on the other. VPPs demonstrate the potential of the energy cloud to deliver value to a number of stakeholders, including energy consumers (e.g., lower costs and new revenue streams), utilities (e.g., avoidance of capital investments in grid infrastructure or peaking power plants), and transmission grid operators (e.g., regulation ancillary services such as spinning reserves).

The emergence of the VPP model is proof that the energy cloud is maturing rapidly. Ultimately, the energy cloud will integrate multiple networks of VPPs and other assets to deliver these benefits to a broader cross-section of stakeholders.

Section 3

THE ENERGY CLOUD AND THE EVOLVING UTILITY

3.1 Gauging the DG Threat

Although many utilities have expressed legitimate concerns about declining revenue at the hands of increasing penetration of DG technologies and energy efficiency measures, the emergence of the energy cloud provides opportunities for utilities to capitalize on this changing landscape. Few dispute DG's inevitability as an inexorable force on the grid. In Europe, the rapid growth in DG has been a key contributor to a more than $500 billion reduction in market capitalization for the top 20 European utilities between 2008 and 2013. This was partly attributable to wholesale electricity prices dropping nearly 50% since 2010 as utilities were forced to run conventional power generation (fossil fuels and nuclear) at a fraction of full capacity. An increasing number of U.S. states have either begun (e.g., New York, Hawaii, and California) or are moving toward (e.g., the Carolinas and Florida) regulatory changes to address the rapid growth of DG. Faced with this reality, utilities will need to make significant investment in modernizing the grid to be able to integrate higher levels of DER.

While the speed at which these events will unfold will vary across specific geographies, the general trend is undeniable. Some utilities are justifiably more alarmed than others, as the degree and rate of impact from demand-side technologies is expected to be quite different across individual utility service territories and countries, especially as the tapestry of DG technologies includes varying degrees of intermittency and load profiles. The result will be a complex array of DG, and more broadly DER, across individual utility territories. Factors such as regulation, incentives, fuel costs, technology, electricity costs, and consumer engagement are examples of the various factors that will affect the rate of change within a given market.

In all cases, DG's emergence will also represent an important opportunity for utilities to adapt their services beyond the traditional focus on baseload generation and the T&D infrastructure necessary to deliver wholesale electrons. These opportunities are summarized in the strengths, weaknesses, opportunities, and threats (SWOT) analysis outlined below. Some utilities have shown a greater willingness to embrace these periphery opportunities and have gone on the offensive by deploying technologies and solutions that are likely to sow the seeds of the future energy cloud landscape. Many others have taken a wait-and-see approach—either because they have more flexibility in their approach due to a more stable asset mix or because they face regulatory constraints that limit their range of responses. In the latter case, utilities may benefit from being insulated from the advance of DER for the time being or remain steadfast in the belief that DG will not be a disruptive force.

Table 3.1 Utility SWOT in the Energy Cloud

Strengths	Weaknesses
» Key player in maintaining and operating incumbent electric grid » Integrated operations and business units » Existing relationship with customers » Access to capital	» Inability and/or reluctance to evolve » Heavy reliance on centralized generation and physical T&D » Regulated entities face heavy scrutiny and long processes » Workforce with limited operating experience in competitive markets and customer focus
Opportunities	**Threats**
» Period of disruption and consolidation » Investment in grid modernization, renewables, DER, and energy storage » Improving customer relationships and loyalty » Diverse business models emerging	» Aging infrastructure » Flat demand growth » Coal plant retirements » New entrants into the marketplace » Rise of DER » Regulatory and policy uncertainty

(Source: Navigant Research)

3.2 Lessons Learned from Telecom

While the energy cloud is still in the early stages of formation, few doubt the significance of its impact over the long term to traditional electric grid architecture and stakeholder relationships. Lessons learned from other industries demonstrate the value to stakeholders of anticipating and planning for disruption. Companies that are able to maneuver quickly in response to a rapidly changing market landscape have routinely emerged stronger and with greater market share than their more risk-averse counterparts.

Disruptive innovation—coined by Clayton Christensen as "innovation that helps create a new market and value network, and eventually goes on to disrupt an existing market and value network (over a few years or decades), displacing an earlier technology"—represents a persistent threat to old-line exposed industries. Two cautionary examples are widely cited in business and technology literature: Kodak and the U.S. Postal Service (USPS). In both cases, the companies held a near monopoly on their markets. Both faced dramatic disruption at the hands of innovative technologies (digital versus film, in the case of Kodak) and changes in the way service is delivered (correspondence by email and the rise of specialized package delivery companies, in the case of USPS).

In its widely cited paper published in 2013, *Disruptive Challenges: Financial Implications and Strategic Responses to a Changing Retail Electric Business*, the Edison Electric Institute (EEI) draws important parallels to disruption in the telecom industry. As discussed in the report, three lessons learned from the transformation of this industry over the past 30 years have important implications for the electric utility industry:

- “First, few anticipated how radical the changes would be in terms of new services provided and the technologies to be deployed;
- “Second, the telephone players acted boldly to consolidate to gain scale and then take action to exploit their market position to expand into new services on a national scale; and
- “Third, the fact that telephone providers pursued new technologies and adapted to the transformation of their business model enabled them to survive as viable businesses today.”

While companies like AT&T and Verizon had the vision to anticipate and chart a strategy to compete in an industry transitioning to wireless, the electrical grid is likely to remain dependent on physical poles and wires infrastructure, forming the connective tissue of the energy cloud. Accordingly, the value of the existing electric grid in the energy cloud will persist and some utilities will continue to thrive by leveraging this infrastructure. However, the value of this side of the business is potentially in decline as greater efficiencies and optimization of existing assets are achieved. When Verizon Wireless acquired the minority stake of Vodafone in Verizon Wireless for $159 billion, the transaction valued the landline business of Verizon at less than 10% of the total market capital of Verizon. This is a reality that many utility industry stakeholders are analyzing. Within this disruption, electric utilities should prepare for and develop plans to deliver value and services in the energy cloud independent of the incumbent grid to maintain long-term viability.

3.3 The Future Utility in the Energy Cloud

Facing declining revenue as customers consume less and produce more of their own power, utilities are faced with large investments to build new transmission capacity, upgrade distribution systems, and invest in new DER businesses. At the same time, it is becoming increasingly difficult for utilities to recover the fixed costs associated with these grid infrastructure investments. Given these challenges, utilities must be adept at playing both defense and offense.

An updated defensive strategy will entail:

» Engaging with customers and regulators to understand customer choices vis-a-vis price and reliability

» Improving customer service and grid reliability at the lowest prices possible

» Finding equitable ways to charge net metering customers for T&D services

» Developing utility-owned renewable assets to appeal to environmentally conscious customers

Playing offense is even more important. Utilities must:

» Create new revenue streams through the development of new business models, products, and services

» Transform their organizations and culture in order to fully integrate sales, customer service, and operations

» Continue to upgrade the grid and redesign operations to facilitate the integration of DER

» Invest in emerging technologies across the T&D grid

» Take a holistic approach to planning that accounts for both current and future interdependencies across technology, regulation, policy, economics, and customer demands

These objectives can only be accomplished by implementing new business models that include developing, owning, and operating DER, such as rooftop solar, customer-sited storage, and home energy management systems; providing third-party financing for DER; and offering new products and services focused on energy efficiency and DR.

Unregulated entities like NRG in the United States and RWE in Europe have had more flexibility to move more aggressively than others in this emerging landscape, taking advantage of opportunities to own behind-the-meter assets not available to their regulated rivals. These providers have looked to integrate DER and DR while remaining flexible in order to adapt to any new, emerging technologies not yet commercialized. Meanwhile, vertically integrated utilities—partly hamstrung by an increasingly obsolete regulatory model—have been slower to embrace this change, but have also been increasingly receptive to the realities of a changing landscape. Although the European grid is further along than the United States with respect to the implementation of new business models, utilities like ESB in Ireland and EDF in France are examples of traditionally vertically integrated entities proactively seeking opportunities to transition their business models. While many U.S. utilities have taken a hard line with respect to solar PV, Southern Co., Edison International, and Pacific Gas and Electric are part of a trend focused on channeling investments into emerging technologies across T&D infrastructure.

States like New York, Hawaii, and California remain at the vanguard of regulatory experimentation in the United States. In New York, for example, regulators have proposed initiatives to transform utilities into distributed systems platform providers, borrowing from early lessons learned in Europe. In this role, utilities would act as the interface between consumers and the bulk power system reflecting an industry trend toward customer engagement. Still, many utilities have narrowed their focus to managing poles and wires, concentrating on the maintenance of grid infrastructure and the transmission of bulk electrons.

Whatever models emerge, the utility of the future will need to be considerably more flexible than many of today's regulatory models allow and embrace opportunities to be uncharacteristically nimble. Those entities that do so are likely to succeed in the evolving energy cloud landscape. Although not exhaustive, several emerging opportunities for the traditional utility are summarized below.

3.3.1 Solar PV Combined with Storage Paves the Way

While DG represents a persistent threat to traditional utility business models, most utilities agree that it is also a promising opportunity for new growth and investment. According to a survey of utility executives, almost half of utilities in the United States are now building new business models around DG, and 55% say partnering with a third-party provider is the strongest investment in the new space, followed by potential regulated investment in distributed resources.[9] Among DG technologies, distributed solar PV represents the most pressing threat and opportunity at the moment. Experience with solar PV provides a blueprint of sorts for other technologies, and, more importantly, may help pave the way for other DG assets to find a beachhead in this burgeoning market.

Solar PV's rise as a DG resource in the traditional utility space has been anything but smooth. Nevertheless, solar has shifted from being what some have argued to be a heavily subsidized indulgence for environmentally conscious households into a pragmatic option for consumers wanting certainty about what their running costs will be next year. The battles waged around net metering, tax credits, usage taxes, and other policy issues have paved the way for the deployment of other emerging DG technologies, such as small wind, fuel cells, microturbines, and micro combined heat and power.

This is perhaps the most important lesson of all for utilities—at the right price, consumers will embrace choice and ownership over their energy consumption patterns with the necessary tools. Proactive utilities are increasingly positioning themselves to meet this demand. Duke Energy, for example, has taken a majority stake in REC Solar following on the heels of Edison International's acquisition of SoCore Energy in 2013.

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[9] *The State of the Electric Utility 2015,* Utility Dive, January 2015, www.utilitydive.com/library/the-state-of-the-electric-utility-2015.

To address issues of DER integration, several business models have emerged from the utility entry into the distributed solar market:

» Utilities invest in solar outside of their regulated territory, which allows them to establish relationships with new customers to whom they can sell additional services.

» Utilities own distributed solar assets within their own territories (leveraging low cost of capital and existing relationships with customers) and earn a return as they would on other investments.

» Utilities offer solar as part of a value-added service model, in which solar is packaged with other services, including distributed energy storage, EV charging stations, or smart thermostats.

Aggregation is at the heart of each strategy, with the goal of greater integration and bundling with other services being the ultimate objective. Under the value-added service model described above, energy storage presents the most exciting opportunity today. With costs declining for community, residential, and commercial energy storage, combined systems are expected to grow alongside solar PV as well as EVs, EV charging, DR, and home energy networks. Consumers enabled with solar storage assets have the potential to become reliable DR market participants. The use of grid-scale storage, meanwhile, is expected to help mitigate imbalances on the grid associated with solar as well as wind's intermittency.

The energy cloud has the potential to provide a robust platform that can enhance utility strategies related to aggregation and synchronization of solar storage resources and services. It can facilitate direct transactions between the utility and the consumer related to DG installations, which, for example, offer an alternative to recouping investment in solar PV through rate design. Once this capacity is online, the energy cloud can enable vast amounts of real-time data related to DG to be tracked and analyzed, helping utilities monitor real-time performance of asset classes (i.e., a collection of rooftop solar assets), better predict future maintenance requirements, and match load and demand with greater precision at the distribution level.

3.3.2 Transactional Energy Trading

Transactive energy (TE) is one way to look at the changes that are already infiltrating energy markets globally, but in different forms and at vastly different paces. In essence, the TE business model, which some have likened to an eBay of electricity, is a natural outgrowth of an energy cloud platform. At the most basic level, TE involves the free communication of information among parties, allowing them to enter into exchanges. A more sophisticated TE market will revolve around the ability of anyone, anywhere to sell energy services into a market exchange program, typically on a forward-looking basis, anticipating shifting demand and supply. If these committed resources lag demand, another market would allow for spot purchases to fill in the gaps.

Examples of thriving TE models exist in other marketplaces (e.g., StubHub, for tickets to sporting events), but it would represent a radical shift in the electricity sector. According to a planning paper by the CPUC, three primary groups of stakeholders would exist in the TE marketplace:

» **Energy services:** Customers, producers, prosumers, and storage providers

» **Transport services:** T&D owners

» **Intermediaries:** Exchanges, lenders, and system operators[10]

For utilities, TE provides an opportunity to provide customers with more independence in how they consume energy and in what form while providing a tool for greater integration of renewables, DER, microgrids, and VPPs. Several trial programs have tested the TE construct in the market. A couple of U.S. Department of Energy-sponsored projects in the Pacific Northwest have demonstrated savings of more than 10% on electricity bills. The PowerMatching City pilot in Groningen, Netherlands is focused on building a peer-based TE grid with the aim of giving consumers maximum choice in device decisions.

A TE market is not without risk. Consumers, for example, would take on greater responsibility with respect to monitoring and responding to market signals. While the use of automation will certainly offset some risk, based on experiences with energy efficiency, the introduction of TE would require substantial investment in customer education programs and trials.

3.3.3 Integrated Service Offerings

For utilities, the end result of the evolution toward the energy cloud will be more integrated service offerings. As different services merge within the electricity delivery market (e.g., security, communication, and health monitoring), siloed services are likely to be bundled in order to take advantage of existing relationships with consumers. There is already a strong precedent in mobile providers bundling cellular offerings and Internet service, for example. Cable companies like Comcast also offer bundled services including phone, Internet, and cable TV. The bundling of services related to residential energy management and a delivery mechanism for receiving pricing signals from utilities is the logical next step in this service maturation.

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[10] *Transactive Energy: A Surreal Vision or a Necessary and Feasible Solution to Grid Problems?,* California Public Utilities Commission, Policy & Planning Division, October 2014, www.cpuc.ca.gov/NR/rdonlyres/F67634A7-4613-4CB0-BB00-C668CED4CEC1/0/PPDTransactiveEnergy_30Oct14.pdf.

Leveraging existing relationships with consumers, utilities have the potential to play a key role in bundling services in the energy cloud. With two-way energy flows, utilities will not only deliver and market energy directly to consumers, but also become consumers and operators of demand-side resources. Some may go so far as to bundle operations and maintenance support for distributed resources, a service traditionally offered by OEMs. While most utilities are working with companies like FirstFuel and Opower to engage the building energy management market, proactive utilities like Duke Energy are acquiring BEMSs as a product offering for their customers.

Section 4

SUSTAINABLE EXCELLENCE IN THE ENERGY CLOUD

4.1 The Evolving Stakeholder Ecosystem

A shift from one-way energy delivery architecture to one that enables bidirectional flow will be a significant instigator of change in the energy cloud, resulting in a transformation of traditional stakeholder relationships. Anticipating and developing strategies to capitalize on new business opportunities in this environment requires understanding changing roles across the value chain. In effect, the energy cloud is expected to lead to greater diversity across the utility and customer pool as new classes of stakeholders emerge, differentiated mostly by their degree of interaction with a more dynamic marketplace. While it is difficult to predict which class of consumer will fare better in the energy cloud—those that embrace new prosumer-led revenue opportunities versus those that prefer the status quo—utilities that cling to a business-as-usual mindset run the risk of obsolescence and potential extinction.

4.1.1 The Service Provider Perspective: Maintaining Reliability Across the Grid's Last Mile

The traditional vertically integrated utility—consisting of generation, distribution, and retail services all under one business—has evolved steadily over the past several decades in the United States in the face of deregulation. In markets where this transition has been most dramatic, traditional utility roles have given way to greater involvement of specialized companies and service providers. Increased competition enabled via deregulation initiatives is expected to accelerate in the energy cloud.

The challenge with a more diverse and complex marketplace and a shift away from vertically integrated operations is maintaining reliability of service. The creation and adoption of uniform standards for operation and compatibility will be a key factor in enabling the energy cloud to deliver improved service. At the transmission level, ISOs have played a key role in maintaining stability and reliability. Meanwhile, the array of innovations increasingly available to traditional utility customers is too extensive and diverse for any one entity to effectively manage. These markets typically fly under the radar at the transformer level, beyond the reach of ISO control.

While the energy cloud will likely increase grid-destabilizing activities across the grid's last mile and outside the reach of ISOs, it will provide a platform for forging new relationships between utilities and service providers to maximize coordination and mitigate risks. For incumbent utilities that prioritize safety and reliability, giving up or conceding control of traditional services represents a significant threat to brand and existing customer relationships. Companies offering specialized services or technologies directly to consumers in turn will need to secure utility buy-in. The pairing of services and technologies facilitated by the energy cloud platform has the potential to maximize value for all parties. Efforts in Europe and New York's Reforming the Energy Vision initiative, which are already underway, have begun to address interesting questions about the future role of transmission system operators/ISOs, distribution system operators, and retailers in the energy cloud. Reform efforts underway in California, as described in Resnick Institute's report, *More Than Smart*, seek to harness the value of customer-sited DG by enabling customer choice through an open, integrated electric network platform.[11]

Similar to strategies executed by innovative telecom companies, bundling of services is a potential product delivery strategy within the energy cloud. While these services may not be provided by a single entity in all cases, partnerships between companies competing for the same consumer dollars will capitalize on potential synergies enabled by the energy cloud (e.g., solar PV and EV cross-marketing use cases explored by the CPUC).

4.1.2 The Custom Perspective: Rise of the Prosumer

As the energy cloud takes shape, consumers will face unprecedented change as well. This complex new landscape will allow for varying degrees of engagement between utility providers and their customers. In turn, this evolution will create new classes of customers, with select groups rewarded for their participation and more passive customers potentially penalized. At present, innovative demand-side management programs are already changing the ways in which customers use and pay for energy.

As the generation and consumption of electricity moves increasingly toward the periphery of the grid, consumers have emerged as a source of new generation capacity as well. Once-passive electric utility customers are becoming proactive consumers, or prosumers, and their numbers are growing. With federal tax credits for solar panels set to expire at the end of 2016 in the United States, growth in the number of prosumers will likely accelerate throughout 2015 and into 2016.

The ultimate outcome of this evolution will be the emergence of TE accounting systems. Rather than a static exchange of electrons for a fixed per-kilowatt-hour price often set by public utilities commissions, TE represents a more interactive approach, with price reflecting more variable factors such as the cost of generation, the cost of transmitting electrons, and market demand. This pricing will fluctuate in a real-time rather than longer intervals set by lengthy ratemaking proceedings. While many utilities have advocated for this approach for years, the technology to collect, aggregate, and analyze the underlying data has not yet been developed for the grid. TE is enabled by smart grid infrastructure, and the energy cloud provides a more robust platform for taking advantage of its full potential through greater integration of data analytics, services, and coordination across the distribution grid.

[11] *More Than Smart: A Framework to Make the Distribution Grid More Open, Efficient and Resilient*, Resnick Institute, 2014.

The rise of the prosumer has made the traditional utility-consumer relationship much more complex. Specifically, interconnecting to the grid to sell excess capacity often entails navigating complex regulatory hurdles and contractual negotiations with energy marketers that have traditionally offered only one-way services. While the energy cloud has the potential to provide a digital bridge for facilitating these interactions and negotiations, the need for a physical interconnection will continue to require time and effort from the consumer.

Intelligent hardware, greater use of data analytics, and dynamic software tools will accelerate the flow of information and enable parties to respond in real time to environmental signals. While utilities are competing to be a preferred provider of DG products and services, competition from third-party service providers threatens to erode existing relationships between utilities and their customers. The energy cloud provides the infrastructure for engaging prosumers, but utility service providers will need to leverage this opportunity in the near future to avoid taking a back seat to more sophisticated and nimble service providers already entering the market.

4.1.3 The Merging of Industries in the Energy Cloud

While the existing electricity grid and the distribution of power has traditionally been the domain of energy utilities, the energy cloud allows for the participation of a broad range of players and industries from outside the energy industry to assume roles and responsibilities. This goes well beyond the customers, stretching across the industrial, commercial, and residential retail landscape. Internet service providers and telecom companies like Verizon and AT&T are already taking advantage of existing relationships with customers and infrastructure to build out offerings that resemble services that have traditionally been offered by cable utilities. Security firms, oil & gas companies, and other diverse players are leveraging domain expertise to capitalize on opportunities in the energy cloud as well, including offering building energy management solutions, combined heat and power, and microgrid-as-a-service offerings.

Smart cities—focused on three overlapping policy objectives: economic development, increased sustainability, and an improvement in the delivery of public services—are emerging as an important platform for early energy cloud development. As described in Navigant Research's white paper, *Smart Cities and the Energy Cloud*, the possibilities offered by the energy cloud vision can play an important role in helping cities balance the often-conflicting requirements for fulfilling these three goals.[12] Smart cities seek to maximize these benefits across several areas that affect electricity use, including building energy efficiency, smart street lighting, transportation, traffic control and parking, and more.

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[12] *Smart Cities and the Energy Cloud*, Navigant Research, 4Q 2014.

This convergence of interests from diverse stakeholders will directly compete with utilities for business. Utilities will likely need to cede some ground to focus resources on their core strengths, but should also look for opportunities to expand service offerings in these areas. In all cases, utilities compete on multiple fronts across the value chain. Thriving in this emerging landscape will require the creation of new business models and innovative strategies for engaging consumers.

4.2 The Future: Open or Closed?

Whatever models emerge, the utility of the future will need to remain flexible and proactive. Those entities that are able to embrace change are best placed to succeed in the evolving energy cloud landscape.

Among technology giants, two predominant business models dictate the way in which consumers connect (and interact) with the broader Internet and the way in which innovation unfolds: open and closed. Drawing again on the analogy of the computing model, this tug-of-war between open versus closed dates back to the introduction of the personal computer, if not back to the mainframe.

Open models seek to facilitate universal access and maximize creativity, but potentially breed chaos, errors, and design catered to the lowest common denominator. Closed systems limit the number of participants and exert more control over the flow of information, but can make it easier to roll out dynamic products while minimizing the potential for error. In more specific terms, it is a battle between the Google, Android, and Adobe business models and those of Facebook, Apple, and Microsoft. Each carries with it specific advantages and disadvantages.

In the energy cloud, the battleground is divided similarly, with advocates of open and closed models both beginning to stake claims. While vendors, consumers, and the broader marketplace are likely to favor the former, utilities will likely favor the latter. In spite of these preferences, open and closed energy cloud models alike must balance the need for access, reliability, safety, and, ultimately, innovation. In both examples, there are many lessons from the Internet revolution that can be applied.

Ultimately, the question comes down to this: will the energy cloud take the form of a walled garden, as CompuServe and America Online attempted in the early days of the Internet and Facebook is doing today, or will it remain an open landscape? Or, perhaps of more relevance to stakeholders, which model best serves the goal of fostering a thriving, ubiquitous, reliable, and resilient grid?

Both open and closed models will likely play key roles, as the energy cloud will serve multiple objectives simultaneously. Innovation is almost never an either/or choice. As most companies have discovered, their innovation goals involve a complex mix of closed and open models, each uniquely tailored to their specific innovation objectives.

For the incumbent utility, for example, objectives remain focused on preserving market share and maintaining safety and reliability while also growing profitability. For the consumer, access to inexpensive and reliable power around the clock and choice in how and by whom their energy is produced remain key objectives. Some stakeholders will seek to maximize either one of these positions, while others will seek to bridge the two.

4.3 Conclusions and Recommendations

Many factors will determine how the energy cloud will evolve across different markets. This evolution is expected to occur at different rates, as penetration levels of DER, changes in regulatory landscape, and consumer attitudes will vary significantly from geography to geography.

While deregulated markets are expected to follow the open computing model—allowing for more experimentation with respect to business models—they may not be the most fertile ground for the development of a viable energy cloud. Greater competition will likely be a boon for consumers in these markets, especially with respect to the price for service. A lack of standardization and coordination across the system, however, is expected to make it much more difficult to ensure reliable, safe, and cost-effective operation due to a high level of market fragmentation.

Regulated markets following the closed computing model—although potentially stifling competition—may prove to be a more stable platform for a coordinated rollout of energy cloud infrastructure and capabilities. A holistic approach to planning in these markets will support the implementation of broader standards and interoperability that will favor accommodation of emerging technologies and allow for unique services and capabilities to be layered into the system. With a regulatory framework already in place in many markets, an infrastructure for re-regulating around dynamic changes across the distribution grid is already in place. While it remains to be seen whether this approach will be effective in leveraging the broad suite of capabilities offered by a fully functioning energy cloud, early efforts to address market changes across Europe, New York, California, and Hawaii will provide early use cases.

As the energy cloud will ultimately represent a network of energy networks, its development will require a rethinking of standards, protocols, and relationships among stakeholders. Data privacy and security issues will remain paramount in the early stages of evolution. With a slew of innovative technologies gaining market share—solar PV, distributed storage, and home energy management systems—the integration of these assets into an efficient and resilient system remains among the greatest challenges ahead for all energy cloud stakeholders and will likely be where the greatest emphasis on innovation will occur.

Section 5

ACRONYM AND ABBREVIATION LIST

ADMS .... Advanced Distribution Management System

BEMS .... Building Energy Management System

CAGR .... Compound Annual Growth Rate

CO_2 .... Carbon Dioxide

CPUC .... California Public Utilities Commission

DER .... Distributed Energy Resources

DG .... Distributed Generation

DR .... Demand Response

EEI .... Edison Electric Institute

EPA .... Environmental Protection Agency (United States)

EU .... European Union

EV .... Electric Vehicle

genset .... Generator Set

GW .... Gigawatt

IoE .... Internet of Energy

ISO .... Independent System Operators

IT .... Information Technology

MW .... Megawatt

OEM .... Original Equipment Manufacturer

OT .... Operations Technology

PV .... Photovoltaics

SCADA .... Supervisory Control and Data Acquisition

SWOT .... Strengths, Weaknesses, Opportunities, and Threats

T&D .... Transmission and Distribution

TE .... Transactive Energy

TV .... Television

TW .... Terawatt

U.S. .... United States

USPS .... U.S. Postal Service

VPP .... Virtual Power Plant

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SCOPE OF STUDY

Navigant Research has prepared this white paper to provide current and interested stakeholders at all levels of the electrical grid—including utilities, regulators, technology suppliers, service providers, investors, and policymakers—with an overview of the opportunities and challenges offered by the emerging energy cloud. Its objective is to provide an understanding of some of the significant market developments and movements that are taking place as the grid becomes increasingly distributed and intelligent. Note that the report does not aim to offer an exhaustive assessment of these specific developments or technologies; much of this is provided in Navigant Research's in-depth market and technology reports, which are referenced in this white paper.

SOURCES AND METHODOLOGY

Navigant Research's industry analysts utilize a variety of research sources in preparing Research Reports. The key component of Navigant Research's analysis is primary research gained from phone and in-person interviews with industry leaders including executives, engineers, and marketing professionals. Analysts are diligent in ensuring that they speak with representatives from every part of the value chain, including but not limited to technology companies, utilities and other service providers, industry associations, government agencies, and the investment community.

Additional analysis includes secondary research conducted by Navigant Research's analysts and its staff of research assistants. Where applicable, all secondary research sources are appropriately cited within this report.

These primary and secondary research sources, combined with the analyst's industry expertise, are synthesized into the qualitative and quantitative analysis presented in Navigant Research's reports. Great care is taken in making sure that all analysis is well-supported by facts, but where the facts are unknown and assumptions must be made, analysts document their assumptions and are prepared to explain their methodology, both within the body of a report and in direct conversations with clients.

Navigant Research is a market research group whose goal is to present an objective, unbiased view of market opportunities within its coverage areas. Navigant Research is not beholden to any special interests and is thus able to offer clear, actionable advice to help clients succeed in the industry, unfettered by technology hype, political agendas, or emotional factors that are inherent in cleantech markets.

NOTES

CAGR refers to compound average annual growth rate, using the formula:

CAGR = (End Year Value ÷ Start Year Value)$^{(1/steps)}$ – 1.

CAGRs presented in the tables are for the entire timeframe in the title. Where data for fewer years are given, the CAGR is for the range presented. Where relevant, CAGRs for shorter timeframes may be given as well.

Figures are based on the best estimates available at the time of calculation. Annual revenues, shipments, and sales are based on end-of-year figures unless otherwise noted. All values are expressed in year 2015 U.S. dollars unless otherwise noted. Percentages may not add up to 100 due to rounding.

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