GTM RESEARCH
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GRID EDGE

Utility Modernization in the Age of Distributed Generation

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EXECUTIVE SUMMARY

Solar energy growth accelerates power grid modernization. A new level of grid intelligence enables this trend, largely financed by the American Recovery and Reinvestment Act (ARRA). In parallel, extreme weather events like Hurricane Sandy in 2012 have renewed public interest in grid reliability. From a business perspective, the push toward market-based value recovery will slowly but steadily put an end to renewable energy's subsidy dependence.

Together, solar PV, smart metering, and public interest in reliability and value recovery make distributed energy resources (DER) more economically promising than ever. With the rate of smart meter penetration expected to surpass one-third of the U.S. by the end of 2013, as well as with continued investments in distribution automation, the smart grid has evolved past being a loose collection of technologies. It is now a system comprising stocks (e.g., meters and sensing devices) and flows (data streams, further investments), including internal feedback loops and synergies. These synergies are key to achieving cost-efficient methods of low-emission power consumption.

Why distributed resources? Because energy storage, demand response and energy efficiency make the grid more flexible at the consumer level. This is where the market grows: While utility-scale installations dominated solar PV in the past, capacity additions in the residential sector will exhibit the largest growth between 2013 and 2017. This pushes challenges and opportunities toward the edge of the grid, where technology, business processes and regulations need to evolve together – a frontier that Greentech Media calls the grid edge.

The overarching trend is the decentralization of resources. Apart from generation, intelligence and control become more granular, because new complexities necessitate monitoring across many more power lines, feeders and substations. For utilities in deregulated markets, net metering tariffs handicap traditional value recovery. Third-party providers of DER add a new level of decentralized competition.

The bottom line is that electricity markets differ from other markets in that someone needs to continuously maintain the supply chain, the distribution network, or power cannot be delivered. To allow the fair allocation of this cost as well as the value of DER, the utility business model must be modified.

The chief difficulty is that the evolution is still ongoing. DER penetration levels are rising at different speeds in different regions, and the outcomes of trends like customer engagement have yet to be seen. Moreover, use cases for new technologies, such as analytics of advanced measuring devices, are discovered out in the field and need to be integrated into future decisions in an iterative way.

Clearly, the power industry is not the first to undergo structural changes. The telecommunications industry has been restructured before, yet a truly smart grid integrates more networks and stakeholders than have previous paradigm shifts. This creates a need for extensive cross-industry collaboration, leading to strategic rather than opportunistic deployments. As the smart grid evolves from public relationships to network relations, policy and industry cooperation is more important than ever.

Key Findings

1. **High growth expectations for analytics mirror the current grid-edge market situation, evolving from foundational hardware to value recovery orientation.** Capitalizing the benefits of early smart grid investments (such as meters) relies on high-usability information tools. With a CAGR of more than 14% in North America, analytics will be the fastest growing market segment between now and 2020. AMI analytics specifically will be driven by performance targets for utilities, necessitating more transparency around metrics like power interruptions duration and frequency.
2. **The GDP multiplier of smart grid investments has proven favorably high compared to other types of infrastructure investments.** However, the long-term impact upon vendors has yet to be proven, as the recent slowdown in the advanced metering infrastructure (AMI) market indicates. Strategic targeting of emerging markets, both domestically and internationally, will be crucial along the way.
3. **The goals of power grid modernization have become clearer in the past twelve months.** Resiliency has emerged as a stepping stone for long-term reliability. The visibility of power flows in the distribution network is the prerequisite of voltage and power stability at high DER penetration levels. Lastly, energy efficiency has emerged as the short-term goal of environmental sustainability.
4. **Extreme weather events have shed new light on the benefits of distributed automation (DA) and advanced metering infrastructure (AMI),** but the full value recovery from AMI data remains a challenge. DA and AMI are among the most capital-intensive grid edge market segments, but their relative cost compared to power outages is small. Moreover, utilities can capitalize on their benefits without waiting for behavioral changes at large. Not having to send crews to verify service restoration is about as obvious as a benefit can get.
5. **The new visibility in the distribution grid will require new approaches to project evaluation.** In interviews with GTM Research, vendors highlighted the importance of technology deployment and feedback to make use of the whole variety of benefits of sensing devices, including the data generated by these devices. Sustained growth of markets like AMI analytics will therefore require more vendor-utility education on product functionalities, as well as the business processes to incorporate that feedback.
6. **Using standardized modularity to create a plug-and-play environment is one major growth opportunity for the grid-edge market, especially for microgrids, energy storage and solar PV.** The current market is characterized by a lack of building-block technologies that offer both standardized interfaces and individual parts that can be combined in a flexible manner. The cost-efficiency of storage, microgrids (e.g., standards for microgrid integration and power electronic interfaces), and solar PV mounting structures could be dramatically increased if standardized modularity were to be incorporated into products.
7. **Cross-sector companies that leverage the synergies between different smart grid markets are growing rapidly.** Among the Top 20 Energy companies selected by Inc. each year, there are more cross-sector companies on the 2013 list than in the previous five years. These firms conquer niches because they identify synergies, such as those between home energy management and demand response or between solar PV installation and energy auditing.

8. **Customer engagement as a future market segment is not as clear-cut as early enthusiastic opinions suggested.** Smart thermostats and detailed energy reports suggest very different approaches to product design, but to date none of them have triggered the energy personalization trend that could create a similar push as smartphones did for mobile communication. In the end, the extent of customer engagement will depend on the progress of grid automation (e.g., the automation of demand response) relative to the progress of attractive energy-use personalization.
9. **The future U.S. energy storage landscape will see more technological variety and more distributed installations.** The upcoming years will see more battery, compressed-air energy storage (CAES), and thermal storage projects coming on-line, as well as more distributed storage. In the Department of Energy International Storage Database, projects with a rated power of less than 500 kW constitute a significantly larger share in the planned and under-construction project categories than they do in the currently installed project category.
10. **Standards for demand response communication help the technology advance from a niche to a mass-market application.** OpenADR 1.0 was the first standard for a non-proprietary demand response communication interface; OpenADR 2.0 expands upon the original version's capabilities. It creates opportunities for the verification of DR signals and DR adoption in new applications. Most importantly, OpenADR 2.0 is designed to connect utilities with commercial or residential control systems, which is a crucial step toward interoperability.
11. **Microgrids are evolving from military applications to civilian facilities, but the outcome of this process depends on the profitability of grid autonomy.** One driver is the renewed interest in disaster resiliency; another is an enhanced opportunity to optimize the microgrid for specific end-user needs. Islanding control, however, remains a challenge. As bulk power grid modernization continues, microgrids will first need to prove cost-efficiency, given that islanding capabilities create the need for advanced controls that increase cost.
12. **Electric vehicles face an interesting market window, but grid integration projects remain scarce.** In 2013, PHEV sales have increased. At the same time, the average duration of U.S. car ownership has increased in parallel to the improving fuel efficiency of new models. The conjunction of these trends could create a major wave of new car purchases, potentially of electric vehicles. As for grid integration, the limited number of EVs equipped with two-way chargers still creates an obstacle; the lack of standards creates another. Like many grid-edge markets, the EV space will need to undergo an evolutionary process of adoption and testing before large-scale grid integration becomes economically favorable.

1. STRUCTURE AND DYNAMICS OF THE GRID EDGE

1.1 Introduction

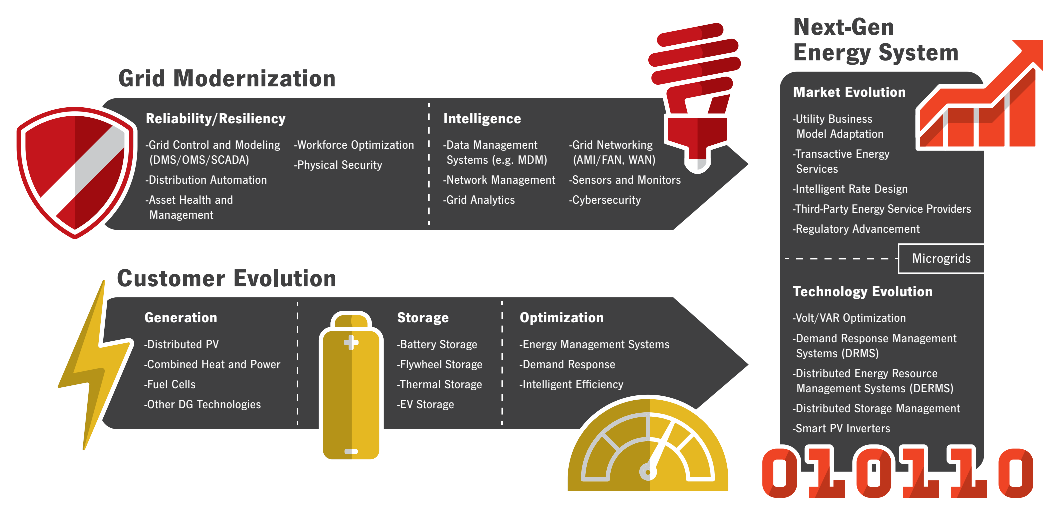
In business, edges represent divergent paths. Industries either continue on familiar grounds or they change direction, integrating more innovation and intelligence. In 2013, the U.S. power sector is embarking on the second trajectory, moving toward the intersection of distributed energy growth, utility business model evolution, and increasing customer demand for efficient energy services. This frontier is what Greentech Media calls the grid edge.

The grid edge comprises the technologies, solutions and business models advancing the transition toward a decentralized and distributed grid structure.

The term “edge” also refers to the distribution grid itself, not only to a divergent path: Technological and economic changes affect the entire grid, but the gap between smart and simple is particularly wide in the medium- and low-voltage part of the network. Currently, the power recipient, substations, and power lines increasingly need to direct and utilize power and information in both directions. The so-called last mile of the grid is particularly affected, as smaller sources connect to the grid at lower voltage. Integrating these sources and delivering maximum value requires new approaches and concerted efforts in business, technology and policy.

Why now? The near-term promise of the grid edge lies in the new level of grid modernization that technologies and vendors can build upon: After smart meter deployments funded by the American Recovery and Reinvestment Act (ARRA), network intelligence has emerged from the playground of public relations to the real-world frontier of network relationships. Meanwhile, the proliferation of customer-side resources such as solar, demand response, and energy storage necessitates the use of these relationships to maintain grid resiliency.

FIGURE 1-1: GRID MODERNIZATION AND CUSTOMER EVOLUTION

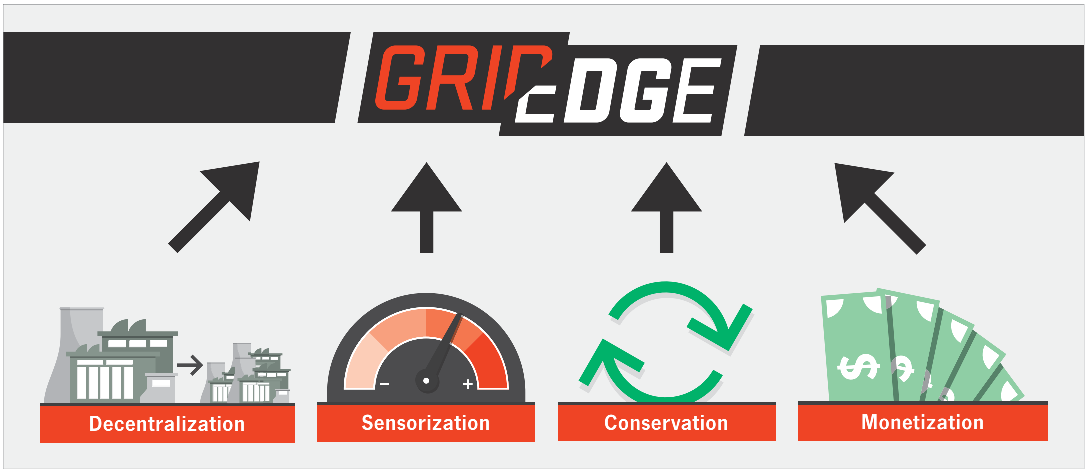


SOURCE: GTM RESEARCH

Contrary to the evolution of the telecommunications industry in the 1990s and the internet in the 2000s, grid modernization is not purely driven by the emergence of new technologies. There is no single revolutionary tool like the transistor for electronics, or glass fiber for telecommunications, that will serve as a technological catalyst for change. Instead, there are emerging approaches to integrating software, hardware and business intelligence that allow high levels of distributed energy integration. It is this convergence of power, telecommunications, and internet connectivity that enables increasingly dynamic grid intelligence. One definition of the term “intelligence” is especially important here, and it is synonymous with self-awareness. The bidirectional flow of power and information is now not only happening, but it is also beginning to be monitored and controlled.

Four forces have driven the progression of the electricity industry, as Figure 1.2 illustrates.

FIGURE 1-2: THE DRIVING FORCES BEHIND ELECTRICITY INDUSTRY PROGRESS



SOURCE: GTM RESEARCH

Decentralization of generation and intelligence: Electricity generation is evolving from a centralized, predominantly fossil-based infrastructure to include increasing amounts of renewable energy sources, both at the utility scale and on a distributed level. GTM Research forecasts one new distributed PV installation every 83 seconds in the U.S. by 2016. While the share of small to large generators in the overall generation mix is still minute, residential solar is steadily increasing its share in overall PV installations. The trend toward decentralization will be furthered by the growth of distributed energy storage and customer load-management options.

As the generation infrastructure changes its topology, intelligence will begin to adapt as well. Local optimization tasks are shifted from central control systems toward the grid edge and are addressed by substations, feeders and generators alike. More and more network nodes are given the gateways and logic to enable them to make data-driven decisions, which are the basis for controlling two-way flows of power and information.

Sensorization: By the end of 2014, 40% of metering devices in the U.S. will likely be digital smart meters. They supply data for the next level of intelligence, the analytics that bring the electrical brain to life. Phasor measurement units, voltage and current sensors are other important facets of the sensorization process. They enable visibility of electrical fast transients in the formerly less controlled distribution grid.

Conservation: The negative kilowatt-hour is making its way to market, partly motivated by Energy Efficiency Resource Standards in 15 U.S. states. Lawrence Berkeley National Laboratory expects electric and gas industry energy-efficiency spending to double between 2010 and 2025, a development that will largely be driven by the electric sector [1]. With highly professionalized demand-response vendors moving into the energy-efficiency market, this trend is likely to continue.

Monetization: Policymakers, utilities, and customers are pushing for a fair allocation of the cost and value of grid modernization. The overall objective is electricity rate structures that reflect the cost and value of distributed energy as reliably, accurately and cost-efficiently as possible.

Along with the monetization process, a hierarchical redefinition of the interface between utilities and consumers is happening. Consumer decisions move into the spotlight, because lower system prices, subsidies, and the surge of third-party financing reduce upfront costs. Demand response and energy efficiency programs continue to grow across the country, and utilities get accustomed to directing and saving, not only selling power. The reign of kilowatt-hours as the only product available to consumers is approaching its end. Customized energy services are replacing power units in the state-of-the-art shopping cart.

Taken together, this coaction of technologies and business ideas constitutes the grid edge: an environment of power where the future will be decided.

1.2 Definition and Taxonomy of the Grid Edge

The grid edge comprises a variety of technologies and services on both sides of the meter. GTM Research created the following grid-edge taxonomy to help visualize the various layers of grid edge and the technologies therein. Many of these technologies are discussed in more detail in subsequent sections of this report.

The physical asset layer is the foundation of the grid edge, as it includes all devices and technologies that physically inject, remove, monitor or control power and its flow in the grid.

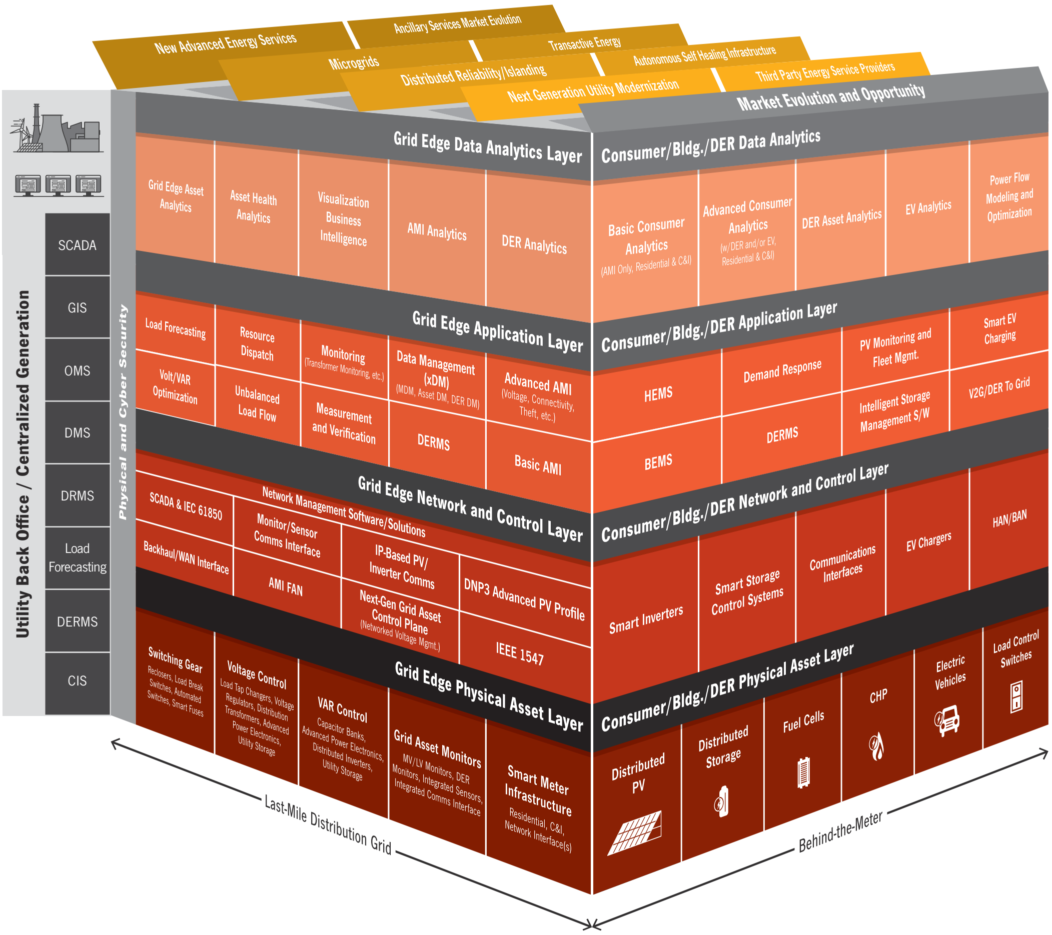
The network and control layer collects, processes and transports signals originating from the physical layer. Its main function is to establish connections between different parts of the network, such as between distributed energy resources (DER) and the grid or between power sensors and the applications on the next layer.

On the grid-edge application layer, these signals are processed into digital information that is further translated into dynamic responses to the actual and forecasted system state.

The software in the data analytics layer extracts high-level information from application layer systems with an inherently predictive character, allowing optimized network operation.

The top of the cube, the market evolution layer, represents the interface between customer-side, utility-based, and distribution-grid applications. It encompasses several regulatory and economic trends that facilitate business models and services not possible in the past, including new architectures such as microgrids.

FIGURE 1-3: GRID EDGE TAXONOMY WITH FOUR TECHNOLOGY LAYERS



SOURCE: GTM RESEARCH

Overall, the grid edge has two essential components. One is the process of grid modernization, which is carried out by technology vendors, utilities, regulators, and consumers. This grid edge component is an interface of interfaces, between utilities and consumers, communication and power networks as well as software, metering devices and home energy management systems.

The second component of the grid edge is a physical part of the power grid, including distributed-energy resources that sit behind the meter, the distribution network, and the devices interacting with that network. Distributed energy resources are forcing the industry to look beyond the medium-voltage distribution grid that operates between 4 kV and 35 kV, down to the secondary customer level at 120 V or 240 V [2]. This network domain is increasingly experiencing voltage and power fluctuations caused by renewables variability and inverter-based technologies, so the opportunity for new technologies is greatest here.

The two grid-edge components, physical and conceptual, converge at the intersection of technology, policy, utility business evolution, and emerging third-party service providers.

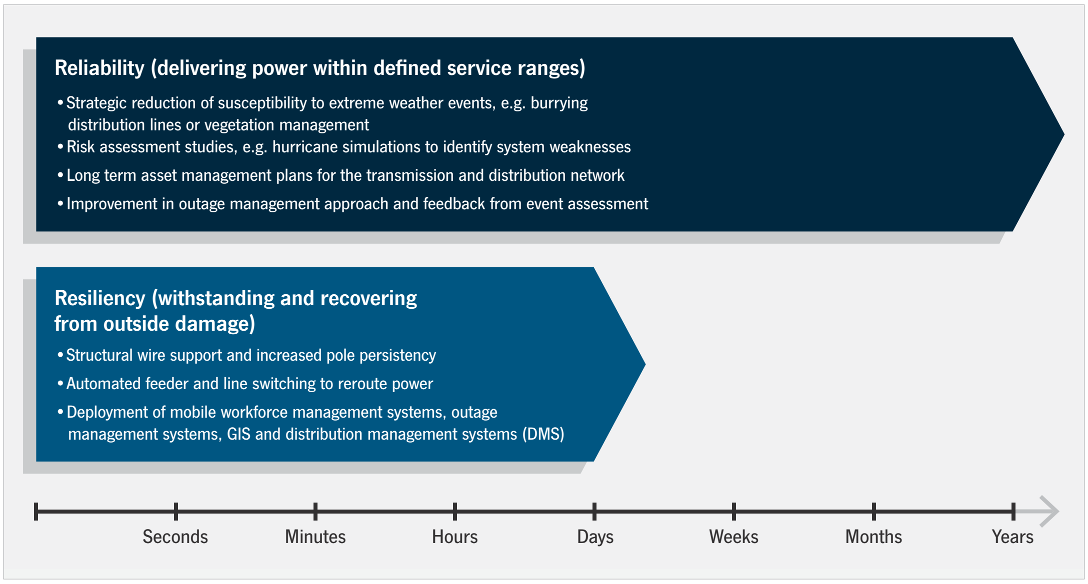
1.3 A Systemic Perspective of the Grid Edge

A systemic perspective helps to understand why grid-edge evolution is beginning to accelerate now, rather than in the past.

In the past, grid modernization efforts have been framed by a somewhat alarmist level of discourse insisting that the power grid urgently needs to be upgraded, but without specifying how or why. This is a systemic problem, because systems only reach their full functionality once their objectives are clearly defined, as well as having the parameters in place by which to quantify progress in the right direction. Metrics matter so much because they foster understanding of individual components and their coaction, and hence enable intelligent system design. In the power sector, parameters such levelized cost of energy (LCOE), energy payback time (EPBT), Energy Return on Energy Investment (EROI), outage duration and cost, and GHG emissions per unit of energy have existed for decades, but they have not been widely used prior to the last ten years.

Partly driven by the devastating effects of Hurricane Sandy in 2012, some grid modernization goals have begun to be clarified within the last twelve months. During this process of clarification, stepping stones via which to reach these goals have emerged. Figure 1.4 illustrates this process for the concepts of resiliency and reliability.

FIGURE 1-4: RESILIENCY AS A STEPPING STONE TO LONG-TERM GRID RELIABILITY



Reliability (delivering power within defined service ranges)

- Strategic reduction of susceptibility to extreme weather events, e.g. burrying distribution lines or vegetation management
- Risk assessment studies, e.g. hurricane simulations to identify system weaknesses
- Long term asset management plans for the transmission and distribution network
- Improvement in outage management approach and feedback from event assessment

Resiliency (withstanding and recovering from outside damage)

- Structural wire support and increased pole persistency
- Automated feeder and line switching to reroute power
- Deployment of mobile workforce management systems, outage management systems, GIS and distribution management systems (DMS)

SOURCE: GTM RESEARCH

While reliability is a long-term objective, systems require resiliency in order to achieve it. What makes a power system reliable is a near-zero likelihood of outages and price surges in a specific electricity market. To avoid both, individual system parts, such as damaged network areas or markets with a resource constraint that is driving up prices, need to be able to detect risky conditions and restore the status quo before damage occurs. The ability to spring back to business as usual constitutes grid resiliency.

While power stability is an obvious goal of the electricity sector, engineers rely on the visibility of waveforms to develop control mechanisms. Sensors and meters that detect risky conditions are the basis for devices that help avoid faults and outages. Visibility increases the control of power at the grid edge.

While sustainability is a revolutionary concept being gradually translated into business processes, efficiency is the bottom-up target for the near term. One definition of sustainability is output maximization with minimum generation of waste. In the power system, waste pertains to losses in lines, losses during energy-conversion processes, and losses at the appliance and consumer level. Energy-efficiency measures reduce this power waste and therefore represent a stepping stone on the path to a more holistic concept of sustainability.

1.3.1 Different Types of Visibility at the Grid Edge

Power visibility: The growth of distributed generation and the integration of renewable energy sources create new challenges for local and global voltage and power stability in the grid. Phasor measurement units (PMUs), sensors and monitoring systems allow power conditions to be tracked down to the last mile of the distribution grid. This is the foundation for the corrective measurements undertaken by control devices.

Product visibility: If consumers are to be engaged in a more informed way, they will need information about energy products that is customized to their level of understanding. This affects the way utilities communicate about their product portfolio, as well as the design of metering device software and home energy management systems. While it would be of limited use to present a diary-like documentation of a dishwasher's power consumption, clear-cut messages about peak demand times and adept, granular usage patterns will be a major driver for grid-edge development.

Progress visibility: Grid modernization is a collective effort that brings together many technologies, as well as an interdependent group of stakeholders. The success of this type of collaboration will depend on knowing about the achievements (or failures) of others. While technologies for centralized generation are standardized, emerging concepts such as microgrids will depend on tailored solutions. This process of standardization (which will also reduce the costs of such technologies) requires data sharing. Yet many important data points, such as wind speeds at hub height, are still considered proprietary. Increased democratization of data across the industry will speed innovation and improve the accuracy of centralized forecasting.

1.3.2 Different Types of Resiliency at the Grid Edge

Power resiliency: Power outages are usually triggered by singular events. If these events lead to a cascading effect, the process can reach the destructive dimension of a blackout. Smart switches can mitigate the effect of these outages, as they react to control signals from local and networked monitoring devices, often early alerts to risky power conditions. This distributed intelligence, coupled with centralized visibility, greatly improves the self-maintenance capability of the system. Self-maintenance (that is, resiliency) is the foundation of reliability.

Data resiliency: Relying on data for critical and day-to-day operations increases the negative effects of errors, lost packets, and sensor failure. As such, the push toward resiliency should focus not only on power flows, but also on information flows.

1.3.3 Efficiency

Efficiency is the hands-on version of sustainability in the power sector. For transmission, efficiency means reducing line losses via technology upgrades. On the local level, distributed generation and microgrids move generation closer to consumption. This can mitigate congestion, which is a major driver of power losses due to heat effects. For each generator or network component, “efficiency” refers to optimized operating conditions. This includes maximum power point trackers for solar arrays or conservation voltage reduction (CVR) efforts aimed at lowering feeder voltage and thus energy consumption.

1.4 Potential for High ROI: Why the Grid Edge Boosts Investment

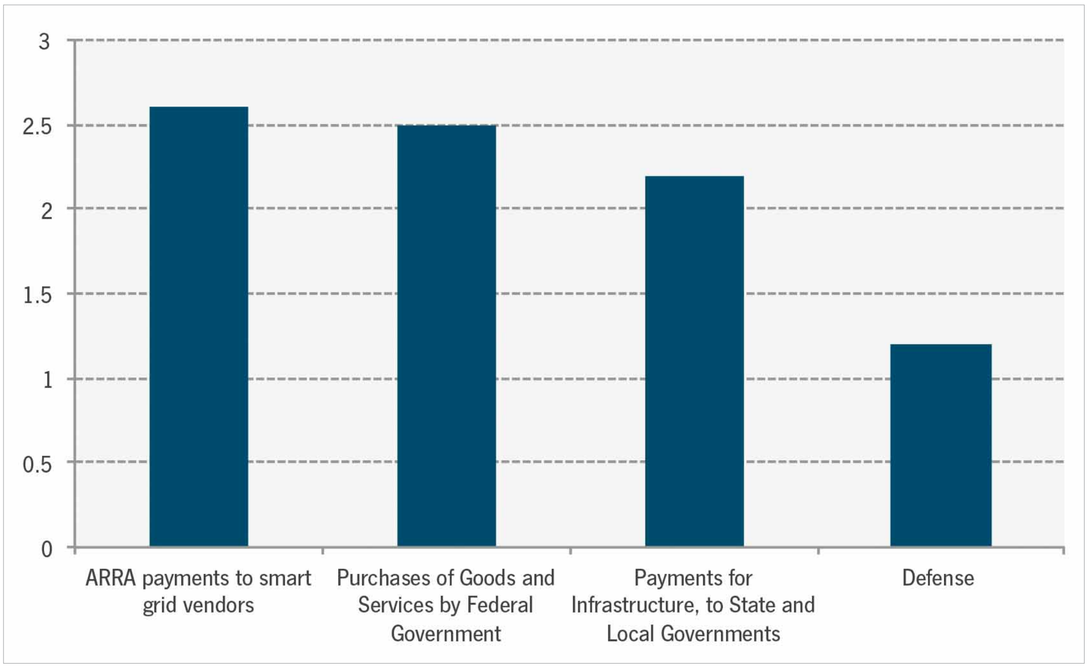
The economic risk of grid modernization used to be the center of attention, but the focus has now shifted to the return on investment. In areas with high rates of intelligent device penetration, hardware expenditures have already been made, and less-capital-intensive business cases to leverage these expenditures are next. These promise higher returns on investment, as software solutions (such as for storage or home energy management) could conceivably be developed in the proverbial garage. Even in Silicon Valley, this is virtually impossible with technologies such as metering devices, power electronics, or transmission infrastructure. The prime example of a foundational investment is advanced metering infrastructure. Largely sponsored by ARRA, the deployment of metering devices created an entrepreneurial drive to develop applications such as grid analytics.

AMI is a foundational investment not only for utilities, but also for the distributed energy market as a whole. For homeowners with solar PV, home energy management systems that integrate energy storage and DR signals can increase the return on their PV systems.

All in all, the coexistence of technologies creates cross-functionalities into which early smart grid investors were not able to tap because the “stock” of smart meters first had to be built up. This accumulation phase caused a delay in business and technology functionalities, but the benefits will become available in the coming decade. This development tells a story of system maturity. The grid edge has become more than a loose collection of technologies on top of the existing power grid; it is now a system comprising stocks (e.g., the distribution system itself, AMI, PMUs, etc.) and flows (data collection, investments), including internal feedback loops and synergies.

Together with existing grid assets of transmission lines and substations, this can create a unique multiplying effect for investments at the grid edge. In a 2013 study of the economic impacts of the American Recovery and Reinvestment Act, the Department of Energy concluded that for every $1 million of direct investment in smart grid vendors, including both ARRA funding and private-sector-matched funds, the GDP increased by $2.6 million [2]. This indicates that grid modernization investments tend to generate more economic output than government spending in other sectors, such as infrastructure payments to local governments [3] or defense spending. Figure 1.5 illustrates these differences.

FIGURE 1-5: VARYING GDP MULTIPLIERS FOR STIMULUS INVESTMENTS



SOURCE: DOE, CONGRESSIONAL BUDGET OFFICE, RAMEY 2011

This comparison can provide a general framework, but multipliers tend to vary significantly by time and scope of analysis. To derive a specific regional “bang for the buck” outlook, recent GDP developments and interest rates need to be taken into account. For individual vendors, the challenge will be to maintain growth despite weakening domestic demand, as well as to strategically seize opportunities in very different local environments regarding DER penetration.

Overall, the market outlook will be driven by two major factors.

1. **Market stamina in the post-stimulus era:** While the Department of Energy is the department with the largest amounts of funds yet to be awarded, 87% of the total appropriations have already been disbursed [4]. In other words, it is now the private sector’s turn, and similar multiplier effects yet have to be proven in that space.
2. **Market accessibility:** The prospect of achieving numerous multipliers can be tempting, but individual vendors will have to look at more specific market conditions and their influence on multipliers, such as:
   - Standardization: Standardized requirements for distribution automation, storage devices or interconnection standards for microgrids increase the market opportunities for vendors as the cost of customization decreases.
   - Cooperation: Sharing data and experiences via open-access platforms is crucial for multiplying prior investments. Entrepreneurial opportunities will therefore depend on utilities’ willingness to publish data in a usable way.

- Timing: Early and innovative entrants into a market will have tremendous growth opportunities, such as the opportunity that EnerNOC took advantage of in the demand response market. But as competitors emerge, incumbents will face more difficulty in sustaining high returns.

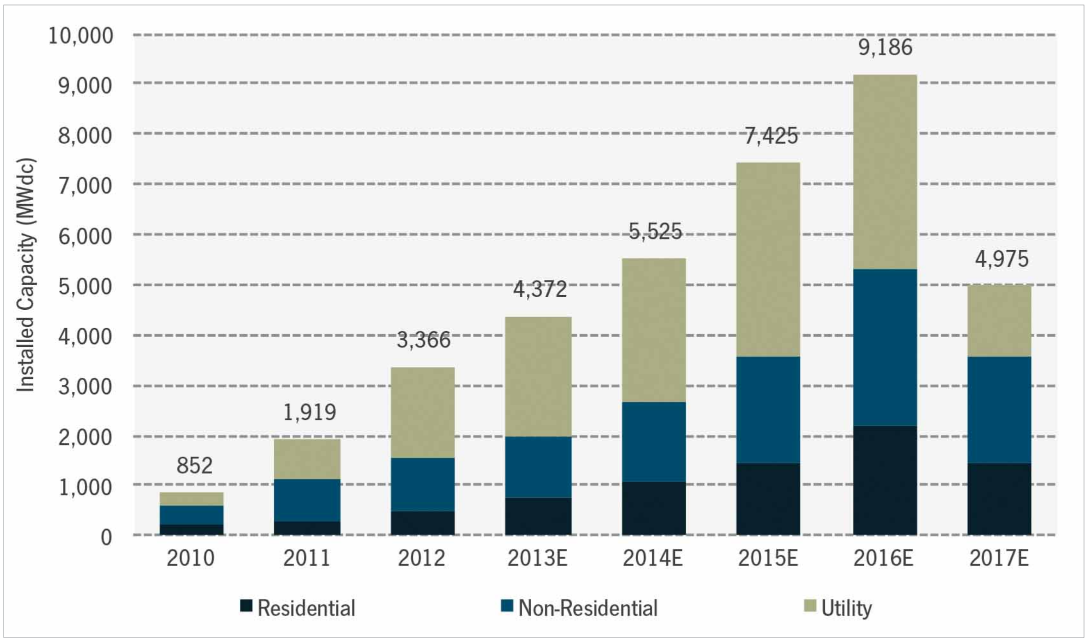
1.5 Grid Edge Market Drivers

Energy security and environmental sustainability are part of the larger context of grid modernization efforts. However, for the following list of thirteen market drivers, GTM Research focused specifically on distribution grid features.

1.5.1 Market Driver 1: Solar Surge

In the second quarter of 2013 more capacity was added in the US residential PV market than ever before (164 MW), up 48% from capacity additions in Q2 2012. In total, GTM Research forecasts that 1,954 MW of distributed generation PV[1] will be installed in the U.S. in 2013, which is more than three times as much as was installed in 2010. While the utility market still comprises the majority of installed capacity in 2013, residential and non-residential installations are likely to exhibit the biggest growth between now and 2017, adding many installations connected behind the meter or to the distribution grid. As the price to install solar continues to fall, PV will soon be cost-competitive with retail electricity across several states. In Hawaii and California, distributed generation PV already serves a meaningful portion of customer load, upending the traditional utility model.

FIGURE 1-6: PV INSTALLATION FORECAST, 2010-2017[2]

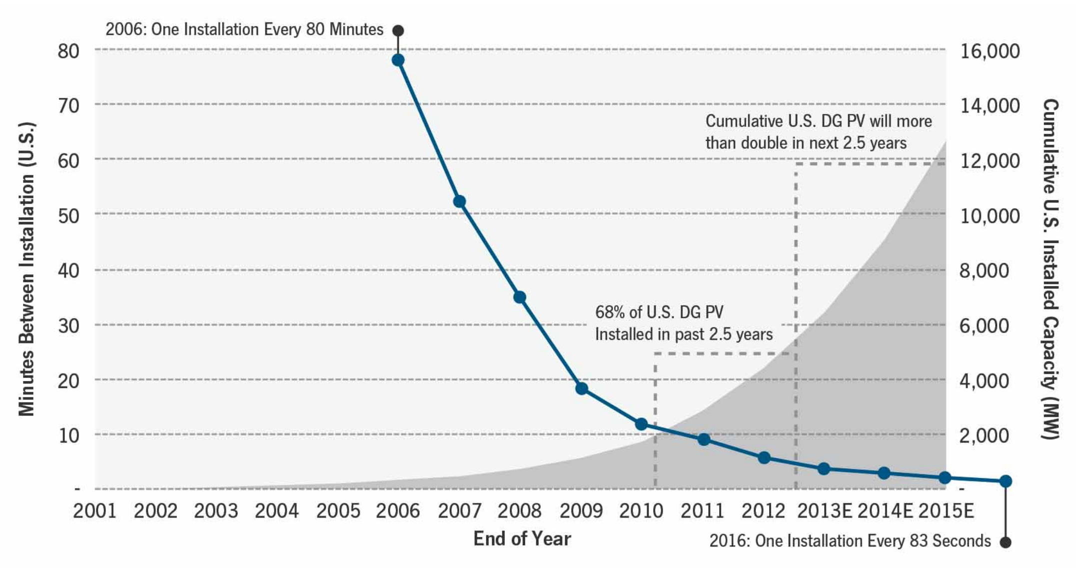


SOURCE: GTM RESEARCH

1.5.2 Market Driver 2: Decentralization Takes Center Stage

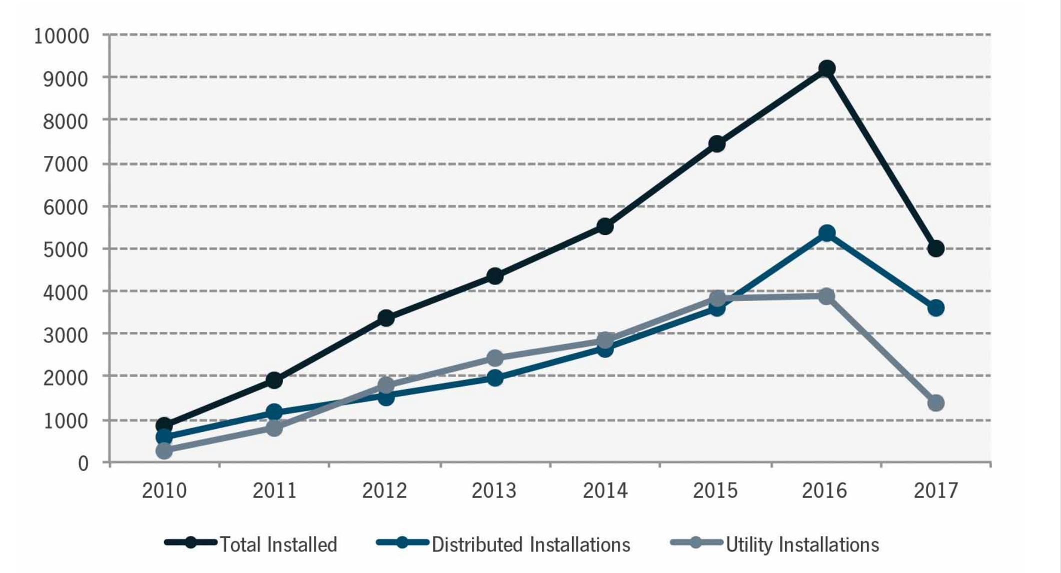
Two-thirds of all distributed PV in the U.S. have been deployed in the last 2.5 years alone, and GTM Research forecasts another doubling in the next 2.5 years. The frequency of distributed PV deployments is increasing rapidly, with one new installation expected every 83 seconds by 2016. By 2017, residential PV will have doubled its share of total PV installations, increasing from 16% in 2011 to 29% in 2017. The following graphs depict these trends. On the heels of distributed PV will come other decentralized technologies, including storage, vehicle electrification and microgrids.

FIGURE 1-7: DISTRIBUTED PV CUMULATIVE CAPACITY AND MINUTES BETWEEN INSTALLATIONS



SOURCE: GTM RESEARCH

FIGURE 1-8: GROWTH OF DISTRIBUTED (RESIDENTIAL AND NON-RESIDENTIAL) VERSUS UTILITY PV INSTALLATIONS, 2008-2018E



SOURCE: GTM RESEARCH

Even wind power is moving toward decentralization. The DOE reports a 62% increase in wind power installations in distributed applications in 2012 compared to 2011 [5] (though utility-scale turbines of >1 MW still represent the largest growth segment in distributed installations).

1.5.3 Market Driver 3: Sandy Sells

Hurricane Sandy focused attention on the crisis-management capabilities of several major utilities, increasing the pressure for them and other utilities to prepare for extreme weather events in the future. During Sandy's outage peak, 8.51 million end-consumers lost power [6]. Concern over past performance is overshadowed only by more disturbing prospects for the future, as the Intergovernmental Panel on Climate Change (IPCC) has concluded that there is a high probability that the intensity and frequency of extreme weather events will increase in the future, and as such, the grid will be forced to endure increasing and more frequent external stress.

The recent trend toward performance-based ratemaking and the expansion of regulatory flexibility reinforces this market driver. GTM Research expects disaster preparedness to engender a major push for distribution automation and grid optimization, analytics, integrated platforms, AMI and microgrid technologies.

1.5.4 Market Driver 4: Smart Value, Smarter Collection

As generation from renewables exceeds local demand and transmission capacity in certain areas, these power sources will increasingly need to be curtailed. This impedes the full recovery of value from distributed energy resources. As investments in renewables continue to grow, so will the incentive to invest in a grid that enables monetization of these benefits. This also includes demand response in the form of "supply response." Recent FERC initiatives to allow the compensation of fast and accurate ancillary services (e.g., those provided by storage and aggregated automated demand response) mark important steps in that direction, as do regulatory efforts to quantify the exact value of distributed energy.

1.5.5 Market Driver 5: Proving the Post-Stimulus Competitiveness of Renewables

Investment tax credits and feed-in tariffs have limited the risk exposure of renewables so far, but the replacement of government interventions with market forces will drive investments in a smarter grid after 2017, when the U.S. federal Investment Tax Credit for solar systems will fall to 10%. Deutsche Bank Research forecasts that the number of states in which solar PV has achieved grid parity could drop from 47 in 2016 to 36 in 2017, which would still be a 70% share [7].

With less government support, renewable generators will have to continue to lower costs in order to expand their market position. As for centralized solar PV, renewable portfolio standards have been the backbone of many power-purchase agreements. The next round will likely be driven by cost-competitiveness.

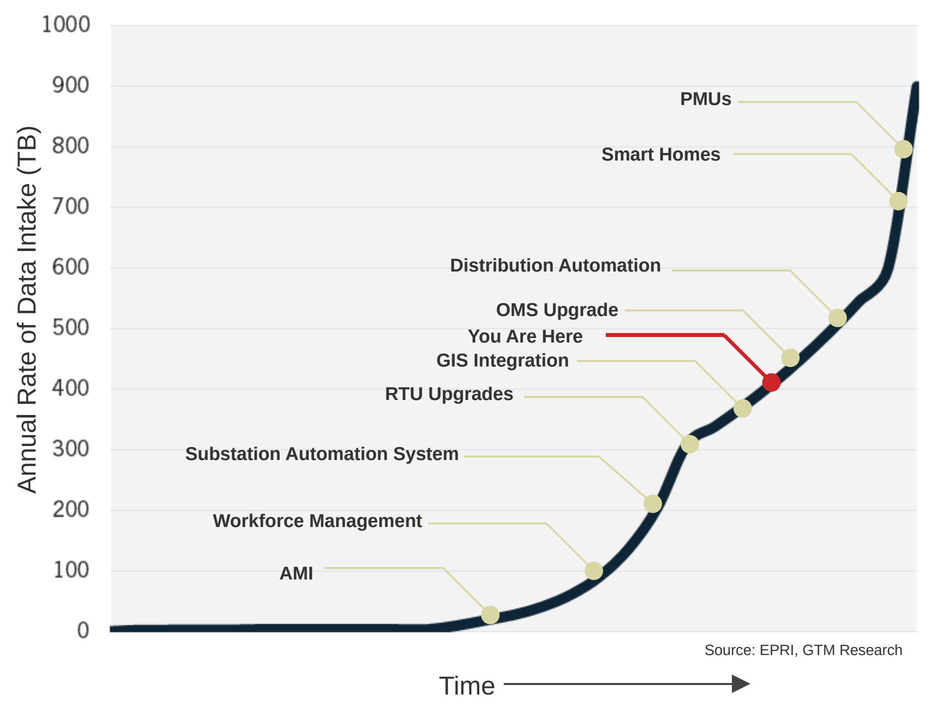
1.5.6 Market Driver 6: The Grid Demands, the Consumer Responds

Demand response growth will be driven by increased standardization and integration possibilities. OpenADR 1.0 laid the foundation for this driver, and its more broadly applicable version 2.0 will allow true value recovery. The Brattle Group forecasts a growth of 56% of peak demand reduction potential between 2010 and 2015, up to 83 GW from 53 GW in 2010 [8].

1.5.7 Market Driver 7: Big Data Hits the Big Time

Data pertaining to experiences of success and failure is a major ingredient in the development of future business concepts. Whether at the utility or consumer scale, analytics supply this information as they are increasingly internalizing terabytes of information supplied by the "internet of things" within the power grid.

FIGURE 1-9: DATA GENERATION AND UTILIZATION



SOURCE: GTM RESEARCH

1.5.8 Market Driver 8: Green Investment Gets Standardized

Third-party financing, green banking, on-bill repayment of distributed energy systems, crowd-funding – many of the finance vehicles for renewables are still new, but every contract signed extends the list of experiences documented by vendors and financial institutions. Standardized investment patterns are bound to emerge, including clear-cut return-on-investment profiles.

1.5.9 Market Driver 9: Soft Grid, Easy Business

Idea-based startup opportunities can capitalize on the many hardware expenditures that have already been made; they represent the next wave of investment in grid modernization. Not only analytics providers, but also consultancies and energy audit companies will profit from the entrepreneurial playground that was created by the power grid investments paid for through ARRA stimulus grants.

1.5.10 Market Driver 10: Smart Upgrades

The U.S. power grid infrastructure is aging rapidly. In New York state alone, 85% of the state's transmission lines were built before 1980. A total of 4,700 miles of lines are expected to approach the end of their viable lifecycles in the next 30 years [9]. With the price of grid-edge equipment falling, utilities will adopt smart technologies to safely extend asset life, as well as to replace aging infrastructure.

1.5.11 Market Driver 11: Increasing Customer Awareness Around Resiliency

While a minor disaster for football fans, the Super Bowl blackout created public awareness of the need for intelligence at the edge of the grid, reminding consumers and regulators of the vulnerabilities of a legacy power grid. Along with extreme weather events, this type of occurrence raises consumer awareness. Although smart-grid solutions are often thought of as more “green” or “clean” than operationally critical, they enhance the foundations of a truly resilient grid.

1.6 Grid Edge Challenges

Without changing the status quo, several impediments may limit the growth of the grid-edge market. These challenges can be grouped into the three broad categories: regulatory, technological and economic.

1.6.1 Regulatory Challenges

A. Lack of homogeneous standards

California’s recent changes to electric interconnection Rule 21[2] are a perfect example of the way that the standardization of application and connection processes for renewable energy projects will need to advance. A pre-application report by the utility now informs a developer about the suitability of the interconnection point before the actual application is submitted. Advancements like this help to streamline the integration of DER, but examples to date are rare.

1.6.2 Technological Challenges

A. Interoperability

> *“It would be extremely convenient if all the differences between networks could be economically resolved by suitable interfacing at the network boundaries. For many of the differences, this objective can be achieved. However, both economic and technical considerations lead us to prefer that the interface be as simple and reliable as possible and deal primarily with passing data between networks that use different packet switching strategies.”*
>
> -Vinton G. Cerf and Robert E. Kahn, IEEE Transactions on Communications, May 1974

It has been 39 years since the creators of the Internet Protocol (IP), which serves as the foundation of the World Wide Web, published their ideas about interoperability. However, this quote just as readily characterizes many of the challenges of operating a reliable and dynamic power grid today. The crucial difference is that during the evolution of the internet, standards emerged in parallel to new technologies, but the challenge facing the evolution of the power grid is that a vast diversity of long-extant technologies are now combined across a power sector. There is an immediate need for well-defined interoperability standards in the following areas:

- **Standards for AMI communications**
- **Distribution automation interoperability:** As grid analytics advance, existing automated network parts are incorporated into the larger grid. As such, now is the time to set standards, as this will create larger markets for distribution automation solutions and avoid the cost of customization.

- **Software integration standards:** Software applications need to communicate the status of a network they are operating in, which necessitates standards. The Common Information Model (CIM) is one step in the right direction, and many extensions for the distribution system (IEC 61968) are under development. MultiSpeak is another key standard used by distribution utilities in the U.S., and its harmonization with CIM is an ongoing process.
- **Interconnection standards for storage, EVs, buildings, microgrids**
- **Standard demand response signals**

B. Large-scale integration of renewable energy

Storage, distribution automation, and HVDC transmission lines are some of the many technologies that can increase the potential for renewable power to contribute to the power supply in a reliable manner, even beyond the often-cited critical level of 30% of penetration. The challenge is to find the ideal, flexible combination. Locally, this means assessing the most viable combination of distribution automation and storage. Globally, it means putting in place transmission infrastructure to allow wide-area balancing, as many studies of penetration levels beyond 25% to 30% have shown the smoothing effect of wider balancing areas.

1.6.3 Business Challenges

A. New utility business models that allow true value recovery from distributed generation, as well as allowing customers to select from among an array of energy services.

B. Engaging the customer at the optimal level

As reports and white papers on customer engagement technologies are piling up, the risk of overshooting consumers' desired level of engagement looms. Customers might desire more direct knowledge of and interaction with the power consumption patterns of their home, but the necessary extent of customer involvement has not yet been definitively determined.

1.7 Grid Edge Gaps

"The current challenges for smart metering and smart grids in Europe are not technical – the technology is there and ready to be deployed – but rather, they are regulatory and political."
-John Stretch, Executive Vice President of Landis+Gyr, 2012

"We've heard a lot about the challenges regarding implementation of demand response in California and the message has been consistent...that the technology is there, the technology really isn't the barrier."
-Jacqueline DeRosa, Customized Energy Solutions, speaking at IEPR Lead Commissioner Workshop, June 2013

If everything is already "there," why haven't outcomes such as drastic reductions in power outages, reductions of the environmental footprint of power consumption, and increases in the profitability of smart grid solutions already begun to materialize? The answer is that a number of significant gaps exist that impede progress from one energy frontier to the next. As opposed to challenges, gaps are not regulatory structures or technical solutions that have yet to be invented. Instead, they pertain to problems that could likely be solved with existing tools, but where a lack of system understanding or missing information has hindered further progress.

Gaps are similar to the missing links in the grid modernization process. Because the grid edge is an interface of interfaces between utilities, vendors, service providers, and consumers, it reaches its highest potential when all gateways are well established. GTM Research has identified five significant gaps which hinder the system from achieving ideal performance.

1.7.1 Technology Gaps

Lack of standardized modularity: Economies of scale drove power plant sizes in the energy system of the past. In order to adapt to the layered and granular smart-grid structure, a different type of technical solutions is required: small-scale modular solutions that are at once both highly standardized and flexible. The goal is achieving maximum efficiency in the production and installation of individual components, while the flexible combination of modules allows maximum adaptation to end-consumer needs and local network topologies. There are three examples within the grid-edge market where standardized modularity could act as a major market enabler.

- **Energy storage:** Mobile battery units that can quickly be combined and scaled to local needs have not yet made it to the market. The idea of mini-modularity has yet to be translated into real-world products.
- **Microgrids:** The power electronics and circuit design of microgrids still rely on tailored solutions for a handful of projects. Modularity of software and hardware, standardized by IEEE interconnection standards but flexible enough to adapt to local network needs, would facilitate a major push for the evolution of microgrid technology from military to civilian applications. Blocks with standardized interfaces and functionalities could be deployed in multiple applications, allowing cost-efficiency gains by scaling up the production of each individual building-block type.
- **Balance of Systems for solar PV:** Costs for balance-of-systems items have yet to catch up with the cost-efficiency gains seen among PV modules. Highly standardized system components that can be adapted to local site structures are still scarce in the market. Promising concepts include the integration of wiring and racking into each individual panel, making the assembly process a lot shorter. Another idea is to create longer strings of panels, such that the overall mounting structure requires fewer elements to combine the different strings. This can be achieved by DC power optimizers, for instance.

Challenges around anti-islanding control for multiple DER units in microgrids: There are still technological constraints that hamper the process of uniting multiple PV systems and other distributed generators in a microgrid. Their simultaneous control is a complex task, especially when it comes to anti-islanding protection. Unintentional Islanding is a system state where a generator continues to supply power during a power outage in the surrounding region, as opposed to doing so intentionally e.g., when power is down during a storm. Distributed energy resources (DER) use different control schemes to detect and prevent unintentional islanding, and existent techniques for individual DER will need to be adapted.

1.7.2 Regulatory Gaps

Limited regulatory evolution around the locational value of storage: Distributed storage has not developed major momentum yet, in large part because its benefits are not reflected by the regulatory and market architecture. Size requirements for participation in frequency regulation markets differ across the U.S.; in some locations, participation is not even an option. This is just one example of the way that lack of clarity negatively impacts the value of energy storage, especially on the utility side.

1.7.3 Business Gaps

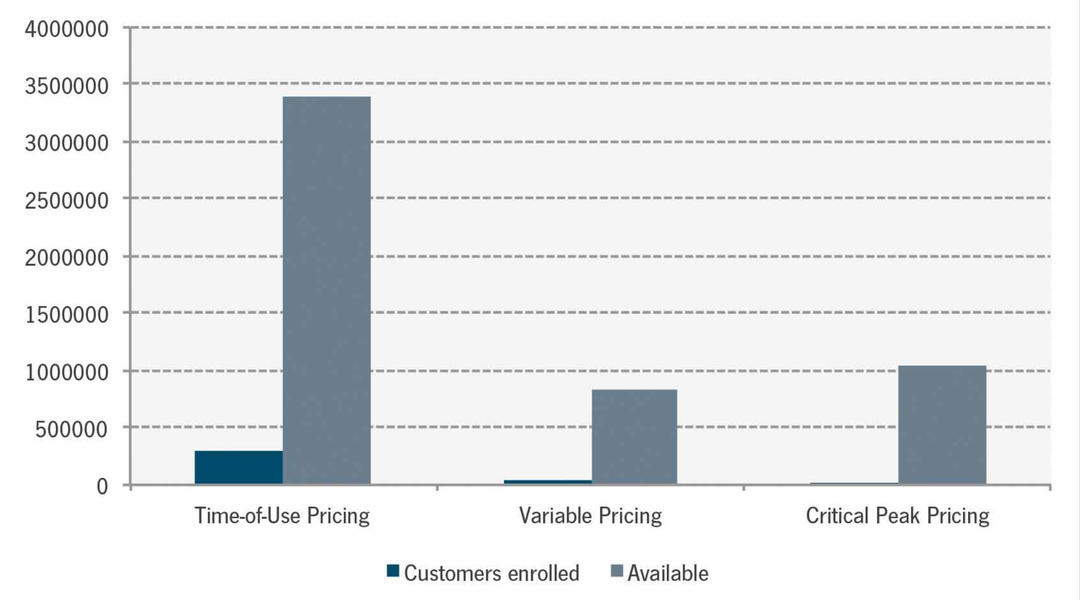
Few feedback mechanisms between utilities and vendors: Many combinations of grid-edge technologies are new, so their true value has to be discovered in the field through rapid prototyping and trials. However, many highly specialized vendors (such as those in the metering space) do not automatically include product evolution after the implementation of newly developed technologies in their business processes. In the long run, they will need faster and more automated feedback mechanisms. This gap could easily be turned into an opportunity for new enterprise analytics solutions.

Few established conventions for distributing upgrade costs among all parties that benefit. Telecommunications and power networks converge, but cost-sharing practices for the two industries have not yet been widely established. The division of infrastructure costs between different stakeholders, such as utilities and telecom providers, could speed up investment decisions, but this practice is not yet widespread.

1.7.4 Information Gaps

Variable and time-of-use rates exist, but even many customers with smart meters do not make use of them. Many industry observers and participants have stressed the lack of incentives for smart power consumption on the consumer side, but in some cases, the reason for this is a basic disconnect between the options that exist and those that are actually being utilized. The following chart below shows the small share of customers currently enrolled in time-based rate programs, compared against the number of customers who could be.

FIGURE 1-10: CUSTOMERS PARTICIPATING IN DYNAMIC PRICING PROGRAMS VERSUS PROGRAMS ON OFFER



SOURCE: WWW.SMARTGRID.GOV

End Notes

1. Distributed generation PV includes behind-the-meter systems installed in the residential and the non-residential sector.
2. This forecast is based on the existence of the Investment Tax Credit through 2016 and no reemergence of the 1603 Treasury Grant Program.
3. The DOE classifies turbines installed close to the load and connected on the customer side of the meter, a distribution grid, or microgrid as “distributed.”

2. THE EVOLUTION OF ELECTRIC UTILITIES

2.1 Shifts in Utility R&D Budgets

One way to maintain a monopoly is to own the supply chain. In the domain of electricity, this supply chain is the power grid. Distribution in particular remains a natural monopoly, while states with restructured electricity markets have introduced competition to generation and retail.

Traditionally, utilities have had relatively minute research and development (R&D) budgets, reflecting their perceived lack of competition in this area. From 1993 to 2000, R&D spending by U.S. electric utilities declined by almost 74%, while research budgets in the sectors of machinery, automobiles and pharmaceuticals all increased [10].

In both the U.S. and Europe, patterns of decline in utility R&D budgets match the introduction of electricity market reforms, most significantly the U.S. Energy Policy Act in 1992 and the EU Electricity Market Directive in 1996. Declining R&D budgets not only mirror the inherent inertia of the utility industry, but they are also a consequence of looming market uncertainty, during which investment decisions tend to become more conservative [11].

However, this trend could soon be reversed due to several emerging factors. First, the realities of restructured power markets are now better understood than during the early years of restructuring. Second, the development of a more intelligent grid offers new opportunities for product differentiation and therefore competition. The ability to distinguish between the quality of different services (e.g., by power quality and outage duration) can be a major driver of utility and vendor R&D spending, provided that an adequate market framework is in place. More than in other industries, market and regulatory forces are interdependent in the power sector. Market access means grid access, as well as accurate pricing mechanisms for different services. Both are virtually impossible without properly designed regulatory mechanisms.

These new opportunities for product differentiation are already having an impact in the industry. In Europe, fifteen large energy suppliers have increased their R&D budgets by 40% between 2007 and 2010, including giants such as E.ON, EDF and Vattenfall [12].

Looking ahead, it is likely that utilities will increasingly draw from the R&D budgets of other industries. As telecommunications, power networks, and web applications converge, so too will the R&D spending of these industries. Booz Allen Hamilton lists technology giants like Microsoft and IBM among the top 20 R&D investors worldwide, and the computing and electronics industry alone, which is aggressively expanding into the power sector at the moment, accounts for 28% of worldwide R&D spending [13].

What motivates companies to spend money on R&D? Studies have identified two large groups of drivers [14]. On the supply side of the market, these include technological changes and industry restructuring, which generates a different environment in which the company must operate. On the demand side, a change in customers' interests, such as a trend toward more functional or cheaper products, can incentivize larger research budgets. Utilities face the following demand- and supply-side issues, with unique needs for research and development on both sides of the market.

Electricity, supply side

- Renewable energy generation at grid scale will require additional investment in reliability. This includes increased reserve requirements and transmission upgrades, as well as improved forecasting tools.
- Distributed energy generation at high penetration levels calls for a more flexible distribution grid, including meters, distribution automation, and power electronics.
- While confronted with new costs and challenges, utilities are increasingly competing with independent power producers and retail power marketers.

Electricity, demand side

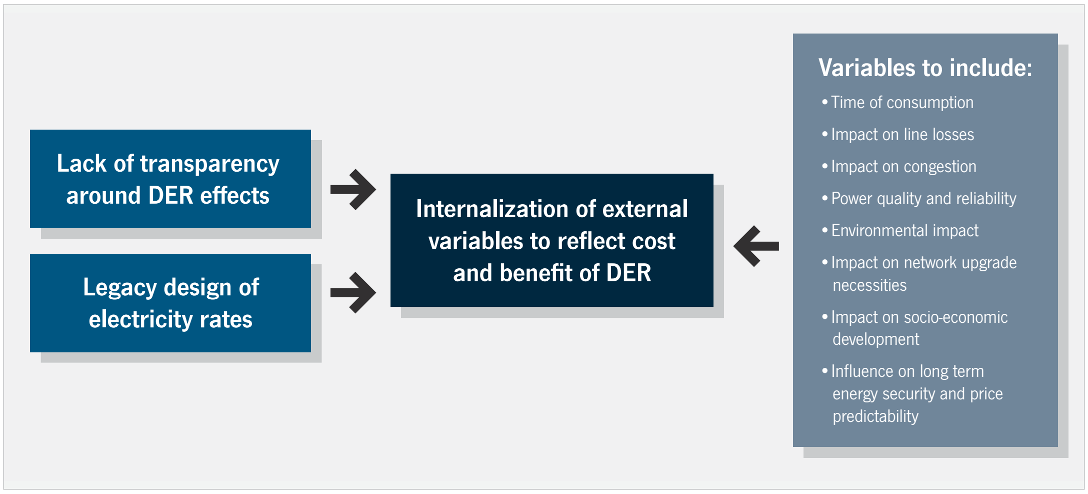
- Recent increases in peak demand in markets like Texas' ERCOT [15] are increasing network stresses, and electric-vehicle charging could add to this trend if not well controlled. Additionally, climate change is likely to raise peak demand for air conditioning during warmer seasons [16].
- Energy efficiency programs have reduced demand in certain areas, leading not only to less network stress, but also to reduced revenues for utilities.
- Distributed energy resources (DER) combined with net metering represent a benefit for customers, while utilities face increased costs of network support. This will continue to hold true as long as the costs and benefits of DER are not properly internalized in rate structures.

2.2 Utility 2.0

According to the U.S. Energy Information Agency (EIA), electricity sales in the U.S. generated $371 billion in retail revenues in 2011, more than three times Apple's global revenue in the same year [17]. This is why business models at the grid edge matter: they help to sustain a multi-billion-dollar industry comprising utilities, system operators, vendors, distributed energy resource providers, and customers.

The shape of the utility business model of the future will depend on how both the cost and value of distributed energy resources (DER) and renewables integration are translated into a revenue stream. The following chart depicts the obstacles that are impeding the creation of new utility business models, as well as the external variables that these business models should address.

FIGURE 2-1: BACKGROUND AND GOALS OF THE RATEMAKING PROCESS



SOURCE: GTM RESEARCH

The following sections address these variables and challenges in greater detail.

1. **Lack of transparency around DER effects.** Distributed energy includes a range of decentralized activities with some impact on electricity demand and supply, but effects will vary by the type of distributed energy (distributed generation, energy efficiency, demand response or storage), the location of deployment, as well as by time and penetration level. Developing metrics that capture the variety of DER and consequences is especially complex while penetration levels are still evolving and system dynamics change.
2. **Legacy design of regulatory framework and electricity rates.** Utilities are known for conservative investment patterns and display considerable inertia. In most jurisdictions, vertically integrated utilities provide both generation and distribution. Rates are based on regulated returns on power plant investments, the cost for network maintenance, and the purchase of wholesale power. While the price of wholesale power changes based on variables such as fuel price, consumers rarely see the system state at consumption time reflected in retail rates, even in restructured electricity markets where customers choose among retailers. Net metering, for example, does not fully account for difficulties regarding the grid integration of PV systems, yet it still compensates PV system owners at retail rates when they feed excess power to the grid.

To advance past this imbalance, the following (mostly) external variables should be internalized in electricity rates and the compensation of DER providers.

Time of consumption and correlation with peak demand: The complexity of serving a load varies drastically depending on the change of demand and supply over time. Time-based rates reflect this variation, but are not yet used widely enough to trigger large-scale behavioral change.

Impact on congestion: Power generation close to consumers can ease network stress, because there is less need for power transmission over long distances.

Impact on line losses: Depending on where and when power is fed into the grid, the distribution of power can be improved or worsened. Distributed generation that supplies energy to remote places using locally sited generation resources will reduce power losses associated with distribution. On the other hand, renewables concentration without adequate transmission infrastructure will overload local lines and increase losses.

Power quality and reliability: Performance- or incentive-based rates, including penalties for not meeting performance targets, already exist in many U.S. states, but their heterogeneity makes the comparison of outcomes and impacts difficult.

Environmental impact: Water, air and land have an implicit value to their users, but changes to this resource base are rarely part of financial transactions between utilities and energy providers. The displacement of fossil-based power generation by renewable energy reduces environmental impact, such as air pollution and GHG emissions, which should be factored into the value proposition of renewables. Additionally, decentralized generation close to consumers lowers transmission and distribution losses and therefore fuel consumption.

Impact on network upgrade necessities: If variability and transients are well controlled, DE can extend asset life and allow postponing investments in new power lines or substations. In the long run, high penetration levels will require investments in distribution automation, analytics and cybersecurity in order to handle altered network dynamics.

Impact on socioeconomic development: Concentration of knowledge in a certain area, such as the cluster of solar PV expertise in California, likely has a positive impact on economic competitiveness. Regional energy scarcity and high price environments, however, tend to have the opposite effect.

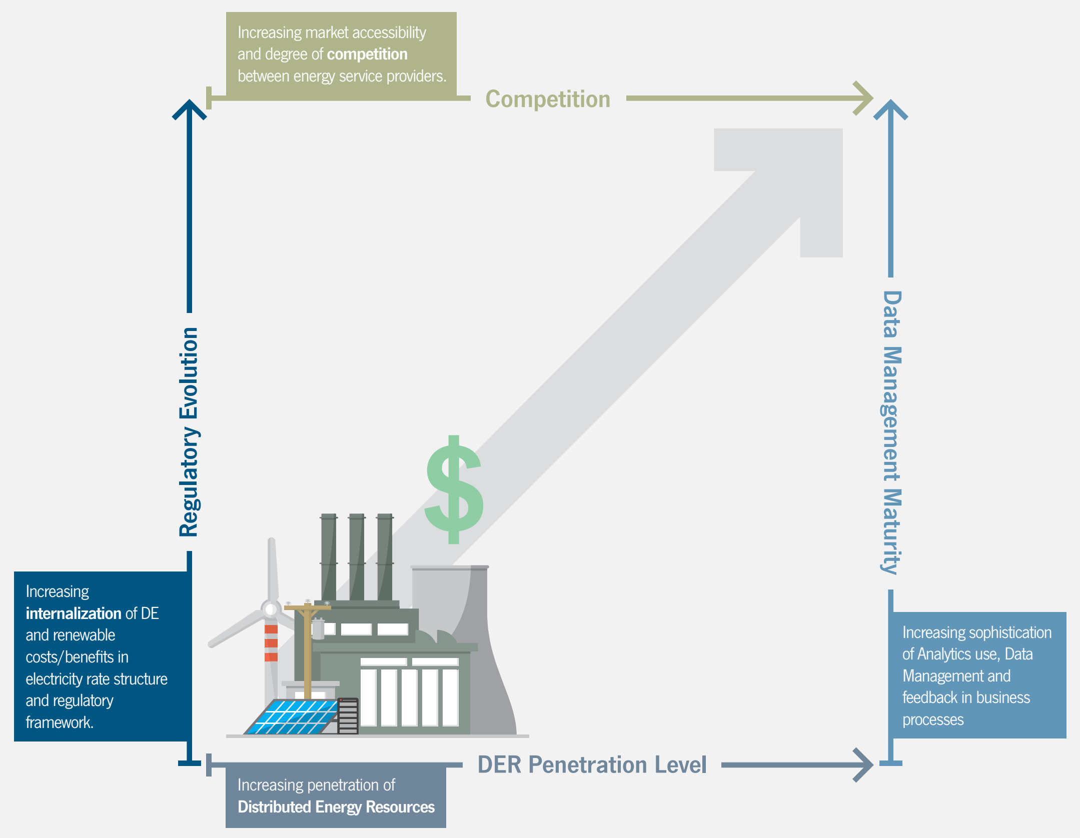
Influence on energy security and long-term price predictability: Because DER operate largely independently from fuel prices, they increase long-term energy security and decrease price vulnerability.

Given the number of variables involved, the evolution of the utility business model is anything but a closed circuit – instead, it is an open-ended process. Factors impacting this process include:

- **Data management maturity:** The degree of standardized data sharing, analytics use and systems interoperability
- **Regulatory evolution:** The internalization of DER costs and benefits in rate structures, as well as rewards and benefits for utility performance
- **DER penetration:** The share of DER in the power grid in terms of load and generation
- **Competition:** The degree of market accessibility for different providers and the degree of competition between them, which is directly related to customer choice

Depending on the progress along each of these axes, several trajectories are possible, as shown in the following figure.

FIGURE 2-2: UTILITY BUSINESS MODEL DEVELOPMENT SCENARIOS



SOURCE: GTM RESEARCH

The DE Axis

Distributed energy growth without adequate cost allocation creates more incentive for ratepayers to "abandon ship" and install their own DE systems. As a consequence, retail rates are likely to increase, as utilities distribute higher network maintenance costs among a smaller customer base. Without efficient DE value monetization, grid modernization continues to be financed by state budgets, provided that the necessary policy push toward renewables is set in motion. Decoupling utility revenues from sales, as implemented by 14 states across the U.S., allows more automated rate adjustment between the traditional rate cases. However adjustment mechanisms require careful design and need to reflect a broader perspective on energy efficiency and DER effects than lost revenue recovery.

Moving further along the DE penetration axis increases the risk of frequent congestion and outages, as an aging network infrastructure is confronted with new technological challenges. This is because the limited use of analytics and data-sharing impedes true value recovery, which in turn minimizes utilities' motivation to invest in distribution network upgrades. All in all, renewable energy sources fail to depart from their current trajectory of intermittent usage. Demand characteristics are poorly understood and R&D money is often invested in a redundant manner because utility experiences are not shared widely enough.

For investor-owned utilities, public utility commissions across the U.S. might eventually push back against rate increases, putting an end to this reinforcing feedback loop and to utilities' near-term interest in distributed energy investments. At the same time, the gulf separating different categories of power consumers is highly likely to be exacerbated. Those who can afford the high upfront costs of DER opt in, while others are forced to depend on more expensive utility services.

The major risk along this axis is that technologies will be rolled out opportunistically, resulting in uneven growth and boom-and-bust cycles within subsectors, while distributed energy retains its image of being difficult to integrate and thus excessively cost-prohibitive.

The Regulatory Evolution Axis

Regulatory evolution will drive investments at the edge of the grid (e.g. in distribution automation, asset management and smart meters), even without distributed energy growth. This can be attributed in large part to the aging U.S. network infrastructure: Investments that in the past might have been postponed are becoming more attractive as better performance and reliability begin to be rewarded.

The Data Management Axis

Operational benefits from AMI/grid/enterprise analytics improve utilities' performance, allowing them to delivering better energy services at lower prices. Progress along the data management and regulatory evolution axis will likely occur in parallel, because the two factors reinforce each other. More sophisticated data management enables easier regulatory evolution. Conversely, regulatory evolution pushes the use of analytics forward, because utilities aim for maximum value recovery.

The Competition Axis

Progress along this axis will occur in parallel to regulatory evolution, because only increased market accessibility will allow competition for the best DER services. The first phase will be characterized by market exploration, wherein many new companies will emerge and try to leverage the benefits of the DER market. Along the way, consolidation can be expected, based on the ability to foresee market gaps and adapt to changing circumstances, such as higher rates of DER penetration, along the way.

Diagonally Upwards

Data sharing and standardization are increasing in parallel to DER growth. In this scenario, the locational and time-dependent characteristics of DE services are beginning to be more accurately reflected by rates. Progress along this path makes it more profitable for both the utility and third-party providers to provide a range of DER services, such as demand response, energy efficiency, distributed storage, and home energy management technologies, which in turn encourages regulatory changes. Data pertaining to a wide range of technologies is analyzed with the help of advanced analytics, clarifying many DER effects that previously were rendered obscure by technical (and hence regulatory) uncertainty. Enhanced understanding of regional DER effects enables the design of customized policies, e.g. subsidies based on DER capacity growth instead of fixed timelines.

The division of services between utilities and third-party providers will depend on many factors, including local network topology and regulatory evolution specifics. However, a certain allocation of roles can be anticipated due to the way the network and market are designed: Energy efficiency on the customer side is likely to remain a third-party business, as utilities historically have stayed away from revenue-reducing measures. On the other hand, services regarding network maintenance and grid interconnection will remain in the realm of utilities. Additionally, utility ownership of PV systems might become more popular in the long run, as system prices continue to decline and older generation facilities approach decommissioning.

2.3 Smart Grid Consumer Engagement

“Consumer engagement” has emerged as a buzzword in the smart grid space. This does not come as a surprise: Consumers pay for a share of grid modernization efforts in the form of rates and taxes, so they need to feel like their investments are paying off. Yet as automation advances, a new question has begun to emerge: If the network is becoming smarter, does the consumer really need to be informed, educated, and engaged? GTM Research expects the rise of customer engagement as a grid-edge market to depend on two major parameters.

- **Success of automation:** Across all network layers, technologies that require less human interaction are emerging, such as automated demand response and home/building energy management systems. As this process advances, fewer instances of customer interaction with the grid will be necessary.
- **Innovation in personalized energy solutions:** Necessity is one thing, lifestyle is another. If personalized energy solutions like smartphone apps and home energy profiles trigger a wave of energy-focused individualization, customer engagement could be a market segment that is rife with growth opportunity. After all, the rise of the smartphone was engendered by highly effective marketing efforts and the personalization of cellphones. As mobile communication emerged as one of the most meaningful social activities, the value added by smartphones and apps led customers to gladly pay the extra cost for these devices. Though it remains unclear whether energy services will make the transition from utilitarian technology to sought-after status items, HEM and customer analytics certainly make that shift more viable, as they provide visibility into energy consumption profiles.

Opower and Nest are two innovative companies that offer a glimpse of possible future pathways for customer engagement. Both are cloud-based analytics startups funded by venture capital, and both use behavioral techniques to encourage customers to engage in more energy-efficient behaviors. Though both companies have partnered with utilities, their respective core philosophies remain distinct. Nest focuses on usability and simplicity, with a central focus on its sleek, minimalist thermostat unit. In contrast, Opower is content-oriented and broke into the utility market by providing detailed energy reports.

2.3.1 The Competitive, Data-Driven Take on Customer Engagement

Opower believes that the human tendency toward competitive behavior can be leveraged to make energy-saving efforts a public, collective undertaking rather than a private activity. Customers receive detailed reports on their energy consumption and how it compares to that of their neighbors. The company partners with Facebook to allow comparison of usage patterns. It started off in the utility market with mailed, paper-based energy reports and eventually expanded into the thermostat market by partnering with Honeywell and providing software for connected thermostats.

2.3.2 The Emotional Take on Customer Engagement

Nest's concept is based on maximum usability. When the consumer first begins to use the product, only the room temperature is displayed on the thermostat's screen, while a more detailed energy profile is available on demand. The focus is on creating positive experiences related to energy efficiency, thus the design of the device is paramount. Over time, the device reduces energy demand based on collected consumption data. Nest started off selling directly to customers, relying on a strong brand-oriented sales strategy. Over the last few quarters, however, the company has embraced a second sales channel, working with distribution and retail power utilities on larger, incentive-based deployments.

3. GRID-EDGE TECHNOLOGIES AND MARKETS

3.1 Introduction

One challenge of the grid-edge market is the degree of granularity it demands. Many technologies mutually reinforce one another (e.g., AMI and analytics), yet their economics differ on an individual basis. Smart software solutions and business practices, rather than materials, are the products developed by market segments like analytics, while solar PV and power electronics are more susceptible to commodity prices. Overall, grid-edge development depends on synergies between different technologies, along with the businesses that leverage these synergies.

Some are already doing so. On Inc. magazine's latest list of the fastest-growing companies, businesses offering services across different market segments are more prominent than ever. Six of the top twenty energy companies listed by Inc. in 2013 are "cross-cutters," combining different types of services, such as home energy management, demand response, energy auditing and solar PV. Two of these synergistic companies, Silver Spring Networks and ThinkLite, even made it onto the master list of the top 50 fastest-growing companies across all industries, not just the energy sector. Many of these companies are early conquerors of niches, highly adept at closing gaps in supply chains. Silver Spring Networks, for instance, provides a versatile platform via which to connect utilities with consumers' home energy management systems. The company landed a major contract in New Zealand, where a consortium of distribution companies was looking for a product flexible enough to bridge the gap to consumers of various energy retailers.

FIGURE 3-1: CROSS-CUTTING FIRMS ON INC.'S 2013 LIST OF TOP ENERGY COMPANIES

Company	Sectors
Silver Spring Networks	Energy management software for utilities and consumers, DR, communications for DA
ThinkLite	Energy efficiency, lighting
Next Step Living	Energy audit, solar PV, heating/cooling
Populus	Energy efficiency, energy auditing, community energy management
NTE Solutions	Project development, environmental impact analysis, asset management
Plug Smart	Generation, energy efficiency consulting

SOURCE: GTM RESEARCH

The following section describes the specific function of technologies at the grid edge and analyzes recent developments. The technology groups included are:

- Technologies for the integration of renewable and distributed energy sources
- Analytics (also known as the soft grid)
- Advanced metering infrastructure (AMI)
- Demand response (DR)
- Microgrids
- Energy storage
- Distribution automation (DA) and grid optimization
- Smart thermostats and home/building energy management systems
- Electric vehicles and charging infrastructure

Analyzing recent developments and deployment data for each technology group, GTM Research found the following key trends that will shape the grid-edge landscape in the coming decade:

- **Cheaper solar integration:** Solar PV integration is bound to become more cost-efficient as inverter prices continue to decline, interconnection rules become more standardized, and business processes can be scaled accordingly.
- **Smarter demand response:** The benefits of OpenADR 2.0, a revised data model standard for automated demand response, will be a key input for demand response and the coaction of many grid-edge players. This new standard allows faster implementation of emerging DR applications because it includes testing procedures as well as reporting capabilities that verify load reduction after a DR signal is sent.
- **Need for more advanced sensors:** Challenges to voltage and power stability in the distribution grid create a strong need for the increased visibility of waveform propagation. This “sensorization” process will require both standard and advanced voltage and current sensors. Only time-synchronized and high-sampling-rate devices (such as synchrophasors) are capable of capturing fast transient processes in a way that allows full reconstruction of events that occur on the grid.
- **Discovery of new technology use cases:** The deployment of sensing devices in previously unmonitored network topologies makes the evaluation of projects more important. In interviews with GTM Research, sensor technology vendors highlighted use-case scenarios that often can only be identified out in the field, on the fully operational grid. Evaluation processes and internal feedback mechanisms will therefore gain relevance in the business practices of many vendors, though they are not yet well established.
- **Clouds gain clout in the analytics market:** Several cloud-based analytics platforms have recently entered the market. Cloud computing reduces the need for local server infrastructure and thus significantly simplifies the implementation of analytics. Cost-efficiency gains are likely in the long term.
- **Energy storage’s new image:** Rather than focusing solely on cost, the concept of value is gaining ground and is now discussed in relation to specific applications and their regulatory context, especially frequency regulation. Regarding storage at the grid edge, this process could pave the way for market architectures that will help to catalyze the energy storage market.
- **Smart thermostats, smarter sales strategies:** Smart thermostats remain the most successful solutions in the home energy management space, but sustained growth will depend on smart product combinations, such as smart thermostats and PV systems. Otherwise, the increasing number of different solutions with overlapping functionalities could cause more customer confusion rather than increasing clarity regarding power consumption.
- **Tough times for AMI deployments foster more holistic implementation strategies:** Advanced metering infrastructure is the market segment facing the most turbulent future. ARRA stimulus funding has allowed major leaps forward, but the post-stimulus phase already has its casualties. U.S. manufacturers are cutting jobs and European roll-out programs are being reconfigured in countries such as Germany. Proving the AMI business case will depend on the joint implementation of communication infrastructures and analytics, as operational AMI benefits (such as the phase-out of physical meter reading) alone won’t suffice to support the business case. Overall, AMI infrastructure has to evolve as a foundation for additional grid services in order to ultimately provide utility value.
- **Microgrid evolution depends on the overall pace of grid modernization:** Microgrid applications sit at the crossroads of military and civilian applications; new interest has been driven by increased public focus on disaster resiliency. Commercial deployments remain scarce, and some future projects may require microgrids to become legal entities with clearly predictable value streams.

3.2 Integration of Renewable and Distributed Energy Sources

3.2.1 Framing the Topic

The integration of renewable and distributed energy sources is the most significant systemic challenge of the grid edge. Solving it means managing the variability of solar and wind while limiting costs. More than other market segments, this will require the skillful combination of a range of technologies, including power electronics, sensing devices, and software to forecast the output of renewable energy generators, as well as distributed energy resource management systems (DERMS).

3.2.2 Deployment and Growth Projections

For decades, two distinct questions have been at the core of the renewable energy discourse: Can renewable energy ever be sufficiently cost-competitive to allow high levels of penetration? And if so, is the power grid even capable of absorbing higher capacities from these intermittent resources? The plummeting cost of solar modules and the resulting increase in deployment experiences have triggered a newer version of these questions. With a dual focus on increasing the share of renewables and grid resiliency, are variable energy sources going to remain cost-competitive?

The following developments will likely render the grid integration of renewables simpler and more economic in the coming decade:

- **More cost-efficient PV integration:** The major grid integration tool for PV is the inverter, and prices are expected to come down across all technology types. This trend is driven by further efficiency gains and supply chain optimization on the technical and organizational side, as well as cheaper materials and increased competition. GTM Research expects an average cost reduction of 17% between 2013 and 2016 (factory gate ASP), with the biggest drop expected for microinverters.

  More importantly, however, inverter suppliers are looking to develop and offer more integration tools in their electrical solutions as a means of differentiation, including ancillary services, Supervisory Control and Data Acquisition (SCADA) systems, and energy storage capability. Holistic inverter solutions will drive the potential for higher penetration PV.
- **Declining PV module prices:** PV Module prices have stabilized in 2013 for the first time in years, but they remain far below most expectations from 2010 and before. The majority of states tracked by GTM Research continue to have average installed costs of less than $5/W in 2013, down from $6/W in 2011. Costs continue to fall incrementally, driving solar ever closer to wide-spread retail parity. Additionally, the industry has targeted lowering Balance of Systems (BOS) costs, which now account for 33% -67% of total PV system costs. The reduction of these costs through innovative hardware and operational efficiency will be a key lever in the economic competitiveness of solar.
- **Growth of distributed solar PV:** Residential PV installations will be the fastest-growing segment of the solar market in the coming years. Scale will play the most significant role in driving down costs, apart from business efficiency gains.
- **More wind, lower power cost:** With 13.1 GW of new capacity, 2012 was a record year for U.S. wind power installations, totaling four times the solar PV capacity added that year [18]. This amount exceeded the previous record in 2009 by as much as 30% [19] and led to wind outperforming natural gas as the single largest source of new generation capacity. Wind farms make an important contribution to the cost-competitiveness of renewables, even if they are usually connected to the transmission grid and therefore not an obvious grid-edge technology.

- **Distributed wind becomes more common:** Sales of small-scale turbines have been decreasing in 2012, but the cumulative capacity of turbines installed in distributed applications nearly doubled between 2009 and 2012, increasing from 428 MW to 812 MW according to a recent DOE report [18]. Distributed applications (either connected to the customer side of the meter or to the local grid) accounted for 68% of all installed units in the past decade.

Despite these positive trends, there are challenges ahead. On the technical side, these include:

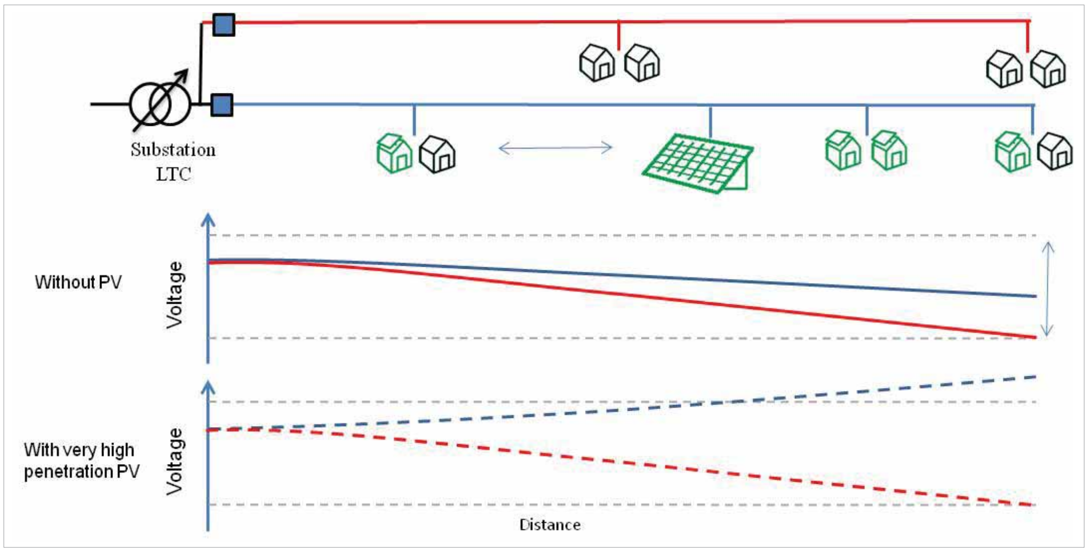
Curtailment of renewables: In summer 2013, the ISO New England provided an illustrative example for this problem. During a July heat wave, when peak supply from Vermont's Kingdom Community Wind farm could have perfectly matched peak demand, transmission constraints lead ISO New England to dispatch diesel-fired units instead [20]. With increasing wind power penetration, wind curtailment has become more common in the U.S. Transmission upgrades are lagging wind capacity additions, but curtailment management strategies are beginning to emerge in markets with high wind capacity, such as ERCOT. Between 2009 and 2012, the share of curtailed to potential wind power generation decreased from 17% to 4% [19].

Intermittency of wind and solar resources: While the variability of solar irradiance is predictable on clear days, cloud-cover patterns are difficult to predict. Inverters support grid stability on a millisecond to minute basis, but large-scale reductions of power output variability require smoothing mechanisms such as storage. Increasing the distance between PV plants decreases power output fluctuation in comparison to individual plant output both for wind parks and solar plants, so optimizing the configuration of the PV fleet is an important task to be addressed in the coming years.

The same is true for larger balancing areas, which tend to display less correlation with local weather patterns and a more diverse portfolio of energy resources. But given the fact that there are 130 Balancing Authorities in the U.S., discovering synergies takes time. Documenting and disseminating performance records might help speed up this process: the Midwest ISO reported saving $60 million to $80 million after combining 26 balancing areas into one large area and sharing regulation reserves [21].

Over-voltages caused by high PV penetration: A high concentration of PV systems in a particular locale can cause undesirable voltage increases in the distribution network. This is a logical consequence of connecting generation sources like PV. However, the edge of the grid is accustomed to voltage drops rather than increases, so voltage regulation at the feeder level is not designed to manage reverse power flow and voltage fluctuation. Integrated volt/VAR control and conservation voltage reduction are technologies designed to address this problem. One of the challenges is to derive voltage regulation mechanisms that can be adapted to different feeder architectures, such as either longer rural or shorter urban feeders. As a long-term goal, a more standardized approach would help ease the process of integrating smart inverters.

FIGURE 3-2: EXAMPLE OF VOLTAGE RISE PROBLEM FOR A HIGH PENETRATION SCENARIO



SOURCE: NREL

Failure to incorporate forecasts into system operations: In order to predict power output across a large number of distributed systems, weather forecasts will need to become more accurate in terms of both the spatial and temporal dimensions. Local weather forecasts are often more accurate, but they often are not shared between forecasting vendors and system operators, as is also often the case with wind speed or irradiance measurements. This impedes centralized forecasting, so overcoming institutional barriers will be one of the major challenges ahead. Rapid adoption of these practices is necessary in order to keep pace with the fast growth of renewables, so amenable policies and streamlined requirements for reporting are key. As an example, the IESO Ontario requires all transmission-connected wind and solar power facilities, as well as distribution-grid-connected facilities above 5 MW, to participate in centralized forecasting. In a truly centralized fashion, all information is available on a single page on the organization's website [22].

3.2.3 Challenges on the Business Side

Standardization: More than 30 U.S. states have adopted interconnection standards applying to customer-sited systems [23]. Still, many of these standards are complex, and companies supplying related services and products often lack ready access to clear-cut information pertaining to timeline, cost, and other important variables. Looking ahead, interconnection standards might need to be adapted as the growth of renewables changes system dynamics over time.

Reduction of soft costs and balance-of-system costs: For a 10 MW crystalline silicon PV system, GTM Research attributes a little over 40% of the total system price to BOS costs. This is a significant share of overall costs, so BOS efficiency gains are the next step following module price reductions. Modular components that are easier to put together will be a major driver of cost reduction, as will the adoption of more standardized business practices. Following the contraction of the module manufacturing market, the BOS vendor space will experience consolidation, with cost reduction being the primary factor behind the determination of which firms gain and maintain market leadership.

3.2.4 Trends, Thought leaders, Vendors, Ideas

Undertakings such as Duke Energy's Virtual Power Plant Project, Alstom's NiceGrid and the ComEd distributed energy resource management system (DERMS) reflect the complexity of this market segment. Projects are very much tailored to local system conditions and points of differentiation from microgrids are often difficult to discern. Furthermore, these projects require high-level cooperation from utilities.

That fact, however, has not excluded startups from the space. Integral Analytics has been working with Duke Energy on its McAlpine Creek project, a microgrid comprising 50 kW solar PV systems, 500 kW battery storage and a DERMS.

An interesting trend is the emergence of a new class of vendors that apply a systems perspective to renewable energy on the consumer side. Eguana Technologies and Princeton Power Systems offer examples of the increasing availability of packaged solutions centered around solar deployment.

3.2.5 Risk and Opportunity

Major opportunity: Taking advantage of the "solar surge" momentum that was created by the reduction of module prices

Major risk: No efficient solutions for the post-FTC period; increase of system costs due to higher reliability expectations, as well as policy uncertainty around federal tax incentives for solar and wind power

3.3 Analytics

3.3.1 Framing the Topic

Analytics function as the brain of the grid edge. This market segment includes software systems that support data analysis and communication across the grid and across utility enterprises. The underlying challenge is data decentralization: as energy generation becomes more distributed, so does information. Data streams from appliances, sensors and DR systems need to be collected and interpreted as rapidly and concisely as possible, especially because of the potential adverse impacts of distributed generation on voltage stability and asset stress. The ability to link and interpret data streams across network nodes is the characteristic that differentiates the descriptive reporting systems of the past from analytics, which focus producing on explicative and predictive information.

Analytics, which GTM Research often refers to as the heart of the soft grid, includes three market segments that differ based on where information is collected and for what purpose.

- **Consumer analytics (also known as Edge Analytics):** How much power is a specific unit (household/EV/building/microgrid) consuming and when is it being consumed? How is this consumption linked to price signals or communication of consumption patterns via social media?

  Examples: Applications could include timing loads and matching their consumption to the power flows of a rooftop PV system or tracking energy consumption patterns from AMI data streams and communicating them via social media. As Opower's products and services illustrate, it can sometimes be difficult to distinguish between demand response technologies and home energy management systems (HEMS).

- **Grid analytics:** Where are grid assets located? What is their physical state in terms of voltage and power flow? Does this state fall within commonly accepted bounds of operational safety? How should grid components react to variable factors such as weather events and outages? Which actions should be taken on the three-phase network based on changes occurring on a single phase?

  Examples: Applications include aggregating performance data from AMI, grid equipment, sensors, transformers or substations; diagnosing outage and transient disruption causes; proactively addressing potential sources of outages or poor power quality; and allowing local equipment or centralized operators to develop control routines to identify and address likely scenarios and conditions.

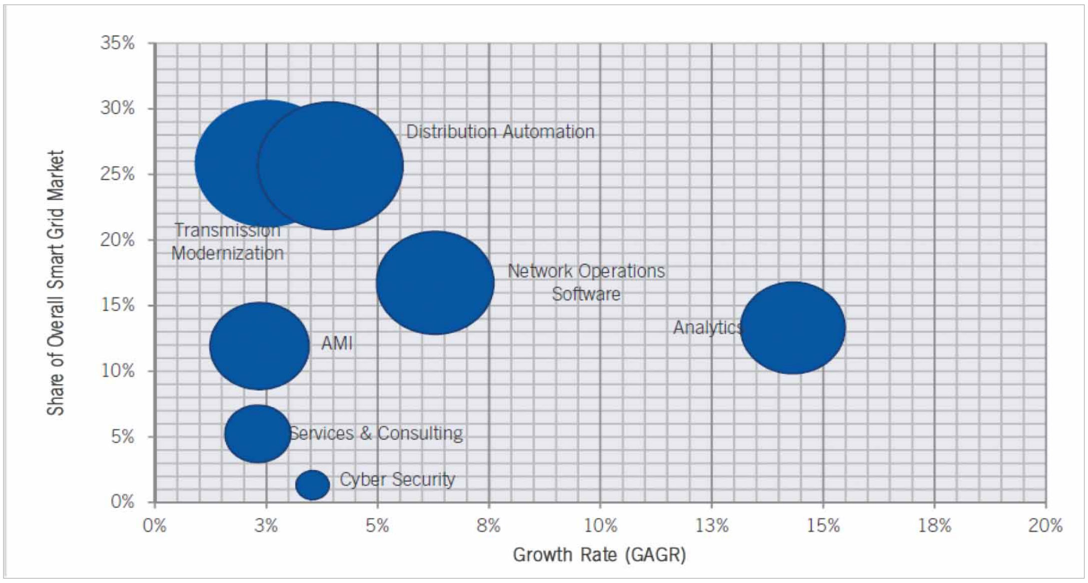
- **Enterprise analytics:** Looking at the different business units within a utility, what are the strengths and weaknesses within the enterprise structure? Which links and information channels between units are important for the support of specific business processes and which should be improved?

  Examples: Applications include enabling forecasting engines to pull data from various operational, customer, and external locations to predict short-term and day-ahead loading, to model local conditions and stresses, and to call on demand and supply resources to economically meet system requirements while reducing stress on system components.

3.3.2 Deployment and Growth Projections

Analytics is an interesting market segment because it excels in terms of both growth expectations and product complexity. GTM Research expects analytics to be the fastest-growing market segment in North America between 2013 and 2020, with operations software and analytics spending together accounting for almost one-fifth of total spending through 2020 – a significant share, especially considering that analytics installations are generally much less capital-intensive than are those in other market segments. Globally, analytics will grow at more than 17% annually (CAGR), more than double the rate of growth of other smart grid markets, as illustrated in Figure 3.3. This outlook mirrors the current situation of the grid-edge market, in that capitalizing on the beneficial outcomes of early smart grid investments, such as meters, relies on high-usability information tools. Analytics help to bridge the gap between disparate data and actionable information.

FIGURE 3-3: NORTH AMERICAN SMART GRID MARKET GROWTH



SOURCE: GTM RESEARCH

From a technical perspective, there are two major challenges for analytics:

1. Integrating data streams from different sources, including unstructured data that is not organized according to a specific data model
2. Processing data sets and storing them in a technically viable and optimally usable manner. Cloud-based solutions, where information is accessed and stored over the internet, are becoming attractive for enterprise analytics and customer information, but there is still considerable inertia on the part of utilities when it comes to disseminating energy pricing and network information to third-party providers.

3.3.3 Trends, Thought Leaders, Vendors, Ideas

Customer analytics have been the center of attention for the past five years, but 2013 marks a shift to utility-scale analytics. Open-source data management platform Hadoop laid the foundation for this trend across a variety of industries, and then this was followed by the launch of Opower's analytics engine Opower 4, which is based on Cloudera's Hadoop infrastructure. C3's analytics engine, which makes use of data that runs the gamut from the demand side to the supply side of the grid, further extends the options available for system-wide analytics. Schneider's cloud-based software platform Orbit is the latest entrant into the market.

Newer, cloud-based services are increasingly integrating legacy systems. Orbit's software platform links mobile workforce and geographic information systems with mobile devices at the utility and consumer level. Against the backdrop of "superstorms" and disaster resiliency concerns, the integration of GIS into utility analytics platforms creates an enormous value proposition for rapid outage management, based largely on the better coordination of restoration efforts that the technology enables. Field crews not only need to know where to go and when to go there, but also what their colleagues are working on. As such, though mobile workforce applications are not new, the combination with cloud computing makes utility-wide data integration much easier.

All segments of the analytics markets will benefit from the progression to utility-scale solutions and the increasing clout of cloud computing. Software platforms geared toward specific applications might still be around, but the true value proposition of analytics arises from data sharing across different business and technology units. For emerging markets, starting off with a high-level platform and branching out into subsections is a much more cost-efficient solution as compared to building interfaces between existing subsystems at a later stage.

3.3.4 Risk and Opportunity

Major opportunity: Cloud-based solutions generating a plug-and-play environment, along with the ability to predict the profitability of future smart grid investments. This could help mitigate market uncertainty in the post-ARRA stimulus phase.

Major risk: Analytics results can be challenging to integrate into ongoing business practices, because quality control might not be applied during the process of learning to deal with new software tools. For utilities, special emphasis should therefore lie not only on the technical components of the process, but also on the organizational integration of analytics and their results.

3.4 Advanced Metering Infrastructure

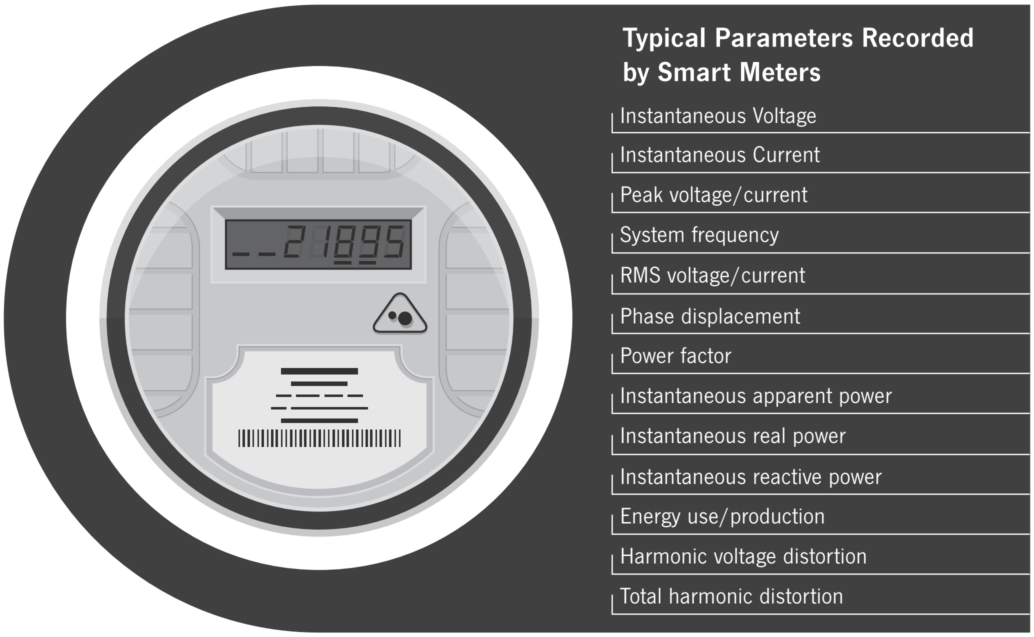
3.4.1 Framing the Topic

If grid edge were a building, AMI would the key to its front door. It is the chief tool in opening up the world of grid-edge intelligence, as it measures and collects valuable data points such as instantaneous voltage and current, frequency, phase displacement, and power factor. Compared to earlier generations of meters, the "advanced" feature of AMI is its ability to enable two-way communication between the utility and the customer.

Advanced metering infrastructure encompasses two types of technology:

1. The digital endpoint metering device that measures time-based consumption and power quality at the customer site and sends and receives measurements, control signals and alerts.
2. The communication infrastructure where information travels between consumer and utility control networks, via either a wireless communication network or powerline carrier communications (PLC) network, among other less frequently used physical mediums.

FIGURE 3-4: TYPICAL PARAMETERS RECORDED BY SMART METERS



Typical Parameters Recorded by Smart Meters

- Instantaneous Voltage
- Instantaneous Current
- Peak voltage/current
- System frequency
- RMS voltage/current
- Phase displacement
- Power factor
- Instantaneous apparent power
- Instantaneous real power
- Instantaneous reactive power
- Energy use/production
- Harmonic voltage distortion
- Total harmonic distortion

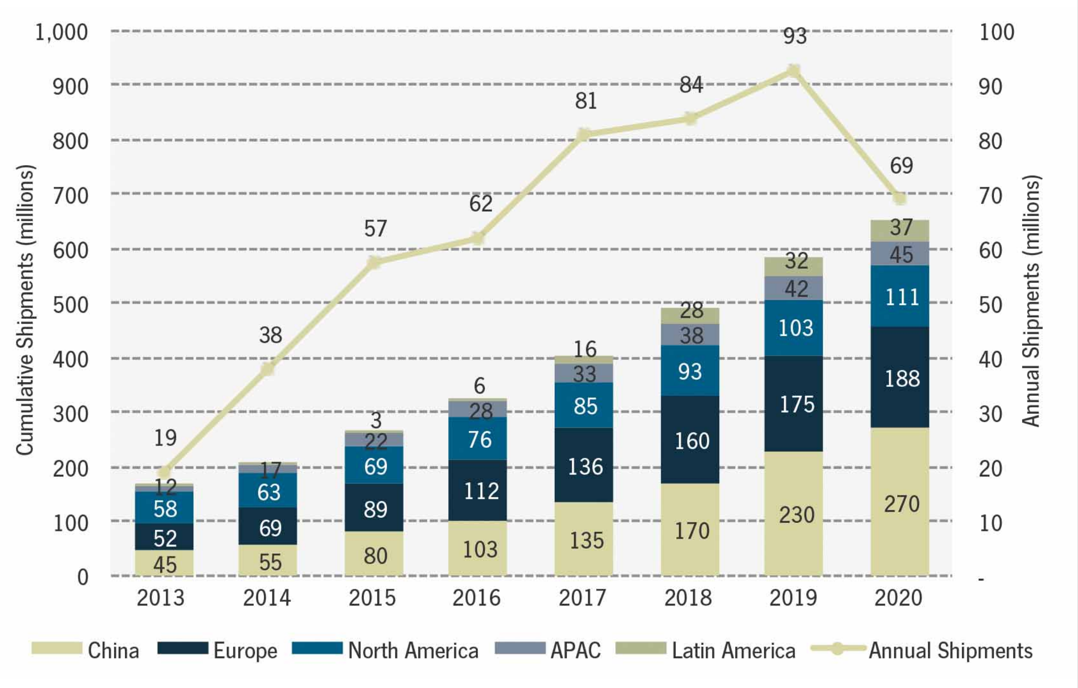
SOURCE: GTM RESEARCH

3.4.2 Deployment and Growth Projections

The federal-government-funded Smart Grid Investment Grant (SGIG) has added 15.5 million smart metering devices to the stock of installed smart meters in the U.S. [33], putting the total number of smart meters over 50 million by the end of 2013. This may sound like an impressive number, but it represents only approximately one-third of the addressable market, as the U.S. has 144.51 million electricity end consumers [EIA 2011, 34]. Supplying the remainder of these households and structures will open up a much larger market.

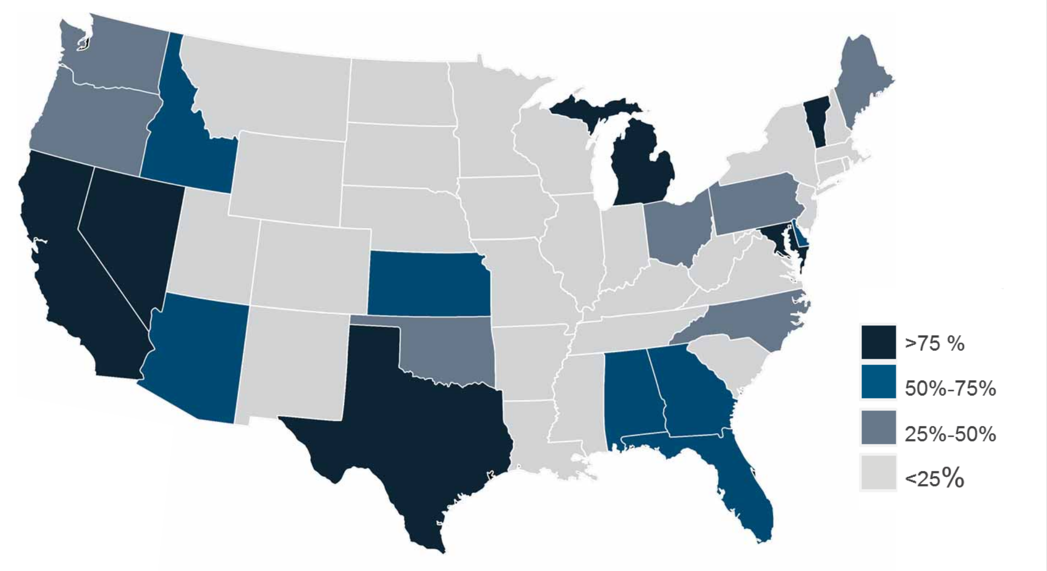
At the end of 2012, FERC estimated a U.S.-wide smart meter penetration level of only 22.9% [35]. As opposed to China and Europe, post-stimulus growth in the U.S. is waning, as North American AMI shipments peaked in 2011. Figure 3.4 illustrates these differences in terms of cumulative shipments. If the market stays on this trajectory, GTM Research expects that t will take until the end of 2014 for average penetration in the U.S. to reach 40%. However, several major deployment projects are underway (including large rollouts being overseen by Ameren Illinois and ComEd), and records documenting the benefits of AMI will be gathered in regions of high penetration. California and Washington, D.C. exceeded the 70% penetration mark in 2012, with several utilities having deployed smart meters to more than 90% of their customer base (e.g., Pacific Gas and Electric, Puget Sound Energy).

FIGURE 3-5: GLOBAL AMI FORECAST, 2013-2020E



SOURCE: GTM RESEARCH

FIGURE 3-6: SMART METER PENETRATION IN THE U.S.



SOURCE: GTM RESEARCH

With 26 states still below the 10% penetration level, the market is there, but it needs to be accessed. In low-penetration locales where electricity is cheap, such as Louisiana, Washington, and Kentucky, the business case for additional installations will depend strongly on the success of AMI analytics in expanding the value streams that AMI can provide.

Investor-owned utilities[4], which are under more pressure to demonstrate strong returns, will continue to drive AMI analytics adoption. Another motivator for AMI installations, even in low-priced electricity markets, is improving the disaster resiliency of the grid. Recognizing and locating power outages is a decisive factor in determining the speed of power restoration, and AMI systems that are tightly integrated with operations units can provide the most rapid identification of outages. Potomac Electric Power Company (PEPCO) in Washington, D.C., for instance, reported that during Hurricane Sandy, outage notifications received from 425,000 homes with smart meters helped the utility speed up the process of fault location. After restoring power, the meters' signals allowed the utility to verify service restoration without sending out crews [24].

3.4.3 Trends, Thought Leaders, Vendors, Ideas

Sustained growth in the post-ARRA era will require innovative approaches. The AMI market is in a turbulent intermediate phase somewhere between hardware and software orientation. On the hardware side, there are many empty spaces yet to explore on the map of AMI penetration. States with AMI penetrations below 5%, such as Illinois, Utah or New Mexico, have the potential to become sizable new markets, but they also carry the risk of long timelines for AMI adoption.

Wherever meters are deployed, the focus shifts to leveraging their benefits. Simultaneously introducing smart meters and DR programs with dynamic pricing is an ideal approach, and it has the added benefit of creating opportunities for both device and software vendors.

With North America representing only 24% of the global smart grid market opportunity through 2020, vendors should have an eye on emerging markets in Europe, South America and Asia. This includes keeping up with the different communication technologies deployed in these areas. While most U.S. utilities use wireless networks to transfer information from meters to the utility, powerline carrier communication (PLC) or cellular networks are preferred in many European countries, which have largely selected domestic vendors, as the U.K.'s recent choice of Telefonica UK demonstrates.

On the other hand, U.S. meter maker Itron was able to land a major contract for France's forthcoming AMI rollout, underscoring the fact that pilot projects are frequently an expansion point upon which large-scale deployments build. Firms involved at that early stage, as Itron was both in France and Hong Kong, will likely have an inside track for winning contracts for wider deployments.

Landis+Gyr serves as another interesting example. While the firm had an involvement in France's AMI rollout along with Itron, Toshiba's recent acquisition of Landis+Gyr raises prospects for the nascent Japanese AMI market, as Japan's rollout plans continue to mature in the post-Fukushima era. If the Japanese market moves beyond the pilot phase, there is a strong chance that it will help the global

AMI market to pick up in 2014. Tokyo Electric Power Co.'s (TEPCO) major contract with Landis+Gyr is a harbinger of this development. The firm will provide communications infrastructure for a 27-million-customer AMI deployment.

Regarding AMI communication networks, the U.K.'s approach marks an improvement in the coordination of smart meter and communication network deployment. Instead of focusing primarily on vendor choice, the orders were clearly divided between smart meters and network providers. A similar coordination effort in New Zealand led to Silver Spring Networks selling its metering communication platform to an entire consortium of vendors. This type of approach makes it easier to plan and facilitate the interoperability of networks and meters with networks – a necessity in the U.K.'s and New Zealand's competitive retail electricity markets. Households switching vendors expect to use the same meter with different communication technologies. The U.K.'s network topology relies on wireless ZigBee to link local meters to nodes, which are then connected to three wide area networks spanning the country.

3.4.4 Risk and Opportunity

Major opportunity: Coordinated implementation of hardware, communication technologies, and analytics into billing and operations processes and systems that reap immediate benefits

Major risk: Without a change of implementation approach, a post-ARRA slack period could occur

3.5 Demand Response

3.5.1 Framing the Topic

Demand response includes all measurements that are taken to change the demand patterns of end consumers, essentially shifting load to flatten the load profile and maximize the use of deployed assets. Demand response can be automated or consumer-driven, encouraged by time-based price signals or incentive payments.

3.5.2 Deployment and Growth Projections

According to a FERC survey, U.S. peak reduction potential was at 66.35 GW in 2012, a 25% increase from 2010 and approximately 8.5% of summer peak load in 2012 [25, 26]. This number is expected to reach 83 GW by 2015 [27]. Policy incentives will continue to play an important role in shaping the market, allowing potential peak reductions turn to be realized. In 2012, only 31% of the total potential was actually achieved.

From a vendor perspective, international demand response markets are becoming more inviting, as they allow firms to leverage existing know-how in less mature and less complex market environments. Post-Fukushima Japan is a prime example of a space where vendors like Comverge and AutoGrid can tap into the hunger of an emerging market. In addition, the European Union is beginning to translate its 2012 Energy Efficiency Directive into a regulatory framework for Demand Response market participation.

The growth of renewable energy could add a new facet to the DR market. As wind or solar power plants frequently are designed with overcapacity to allow them to generate enough power during periods with low levels of wind or sun, they sometimes cause oversupply during favorable weather conditions. With the increasing complexity of home and building energy management, storage devices could help to enable not only demand response, but also supply response.

3.5.3 Trends, Thought Leaders, Vendors, Ideas

Two trends have made the past year particularly interesting in the DR space: the increasing maturity of the demand response market and the expansion of DR from the commercial and industrial markets into the residential market, spurred by the development of OpenADR data models.

- **Competition** around the grid's cooling agent is heating up, because increased availability of DR services is driving down prices. As a consequence, companies are struggling to diversify their services in markets where the proverbial low-hanging fruit has already been picked. EnerNOC, a leading U.S. DR company, has seen falling revenues in the PJM Interconnection market, its prime source of income. The company increased the share of its revenues coming from energy-efficiency services and has invested heavily in cloud-based analytics.
- **Product differentiation** around DR services has reached the regulatory level, allowing for more suitable compensation of DR in wholesale electricity markets. FERC 745 provided locational marginal pricing for demand response, while FERC 755 established compensation for frequency regulation services based on speed and accuracy. These rulings mark important steps forward, as they validate the notion that DR compensation needs to be customizable to local conditions in order to encourage utility investments in DR. One way to achieve this is sharing a certain percentage of a customer's avoided cost among the utilities participating in the DR program. Another incentive could be the compensation of utilities at a certain share of the anticipated returns on investment in generation facilities they would have had to procure without the help of demand response (or energy efficiency).

OpenADR, a data model standard for the exchange of DR messages, has had a major impact on DR's evolution from a niche application to a mass-market tool. Just as protocols have enabled the proliferation of the internet, the standardization of price and reliability signals enables all parties involved in grid operation to speak the same language, including utilities, ISOs, third-party aggregators, homes, and buildings. After a decade of research and testing, OpenADR is conquering market space beyond pilots in industrial and commercial applications. Its 2.0 version features extended data models with feedback capabilities. This means that end-node characteristics, such as load reduction after receiving a DR signal, can now be reported back to DR signal providers [28]. Additionally, OpenADR 2.0 includes a testing program, allowing standardized adaption to new applications, especially in the residential sector. In short, 1.0 was the foundational standard, but the functionality of 2.0 is significantly expanded.

Adoption of the standard is occurring rapidly. EnerNOC is an early adopter that built OpenADR 2.0 into its platform, and Honeywell's ComfortPoint is compatible as well, as are products offered by IPKeys, Fujitsu and AutoGrid. AutoGrid is particularly interesting, as it claims to offer a vendor- and hardware-neutral system, providing a foundation for a potential plug-and-play DR environment.

California's three largest utilities are beginning to test the standard, and documentation of the process will be crucial to improve future performance. The unique challenge in California is that a large proportion of the DR market in the state is already controlled by OpenADR 1.0, and users now must switch to OpenADR 2.0.

Products using OpenADR will likely experience sustained growth in Europe and Asia, while interoperability issues could impede adoption in the U.S..

3.5.4 Risk and Opportunity

Major opportunity: Standardization of DR signals, allowing collaboration and interoperability among a wider range of grid-edge market segments

Major risk: If the increasing variety of DR products is not accompanied by industry-wide information exchange and better modeling capabilities, the benefits of specific DR programs will be difficult to predict, and implementation into daily operations could prove to be problematic.

3.6 Grid Optimization and Distribution Automation

3.6.1 Framing the Topic

This technology segment represents the internal cog wheel of the grid edge. It comprises a plethora of devices working together to reduce network stress and thus power losses, serving the goals of improved operational efficiency and smarter asset management. These technologies "harden" the grid edge, a quality that gained renewed importance in the aftermath of Hurricane Sandy in 2012. Apart from structural wire support and increased persistency of poles, it is distribution automation that lies at the center of intelligent grid strengthening. Automated feeder and line switching, where power is rerouted according to local conditions, has already been reported to reduce the number of sustained outages, as utility EPB Chattanooga witnessed during a July 2012 wind storm. More comprehensive documentation and dissemination of instances that highlight the importance of reaction speed will act as major driver of future investments in distribution automation and grid optimization.

The technologies that make up this market segment are identified in the following table.

FIGURE 3-7: DISTRIBUTION AUTOMATION TECHNOLOGY TYPES

TECHNOLOGY	FUNCTION	GRID-EDGE RELEVANCE
Power quality/voltage monitoring devices	Phasor measurement units (PMUs) and voltage/current sensors track changes in power quality and voltage at substations, feeders and line control points. PMUs are called synchrophasors when measurements are time-synchronized, allowing operators to link and analyze events over wide areas.	**HIGH** – Distributed energy resources require enhanced visibility into the distribution network, where synchrophasors (originally a transmission grid technology) or similar fast-sampling devices are becoming more attractive.
Power quality/voltage control devices	Voltage regulators, load tap changers and capacitor banks allow adjustment of voltage levels and the ratio of real and apparent power (i.e., volt/VAR control). Voltage optimization and conservation voltage reduction are the other two main functions of these types of power electronics.	**HIGH** – Distributed energy sources change local power flow characteristics; they need to be controlled.
Supervisory control and data acquisition systems (SCADA)	These systems collect and analyze measurements and use the results to control substations and feeders.	**MEDIUM** – SCADA systems existed before the advent of grid-edge technology; they could be relegated to substation acquisition by innovations in wide-area communications systems.
Remote-controllable switches, reclosers, protective relays, capacitor banks and substation transformers	Fast-reacting devices open or close circuits in reaction to system changes, such as a voltage drop, to protect system parts like substations from fault effects, such as currents.	**MEDIUM** – This is an established group of technologies to which newer features such as integrated control, sensing, coordination and shorter response times have been added.

SOURCE: GTM RESEARCH

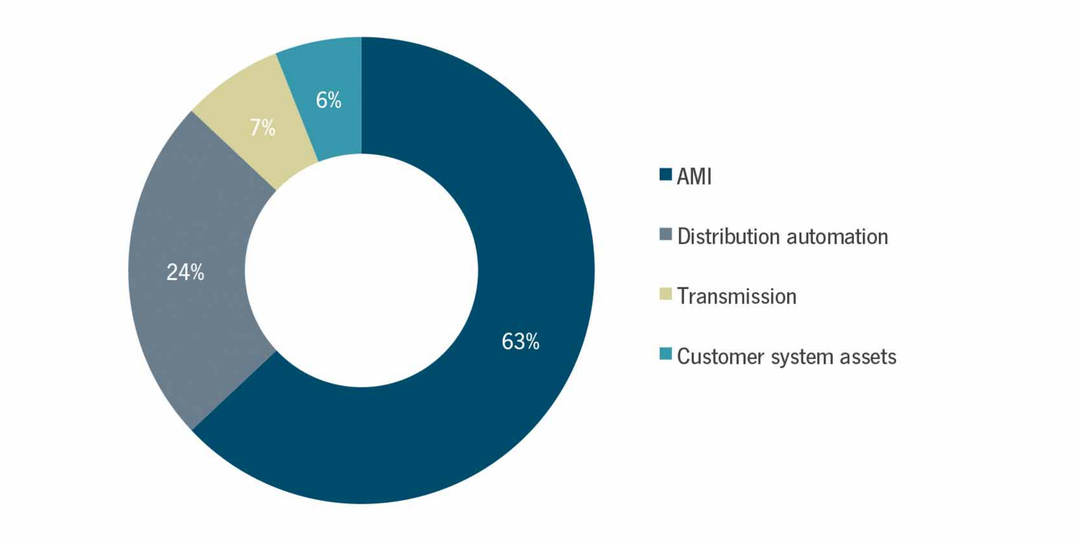
3.6.2 Deployment and Growth Projections

With over $15 billion cumulative spending expected by 2020, GTM Research forecasts distribution automation to be the second-largest smart grid market after transmission upgrades, which is a traditionally capital-intensive process. The market is driven by the recent uptick in interest in disaster resiliency after Hurricanes Sandy and Ike caused billions of dollars in damage. In the aftermath of those storms, distribution system upgrade costs are no longer discussed in absolute terms alone, but relative to the cost of outages.

Between $18 billion and $33 billion in losses have been incurred due to weather-related outages each year over the past decade, according to a 2013 White House report. Even with the lower-bound cost estimate of $18 billion, total Smart Grid Investment Grant spending between 2010 and 2013 ($5.74 billion) accounts for only 8% of the total outage cost in those years.

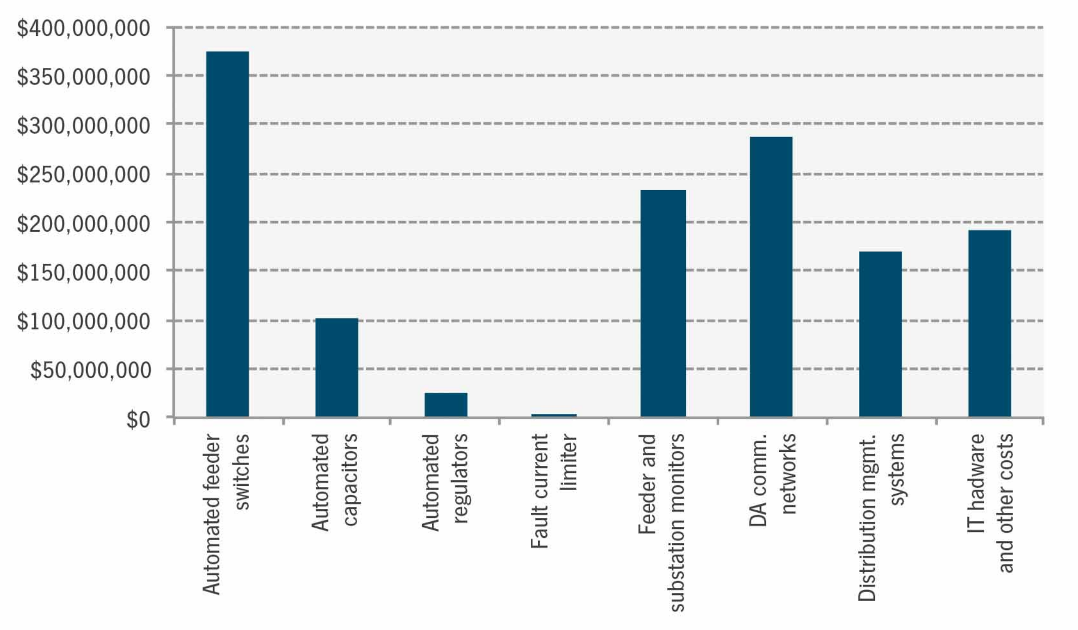
The market has already been the recipient of significant government investment in the past. Receiving roughly $1.4 billion from the SGIG program, which was spent primarily on automated feeder switches and distribution automation communication networks, distribution automation is the second-largest SGIG investment category after AMI expenditures.

FIGURE 3-8: SGIG SPENDING BY TECHNOLOGY



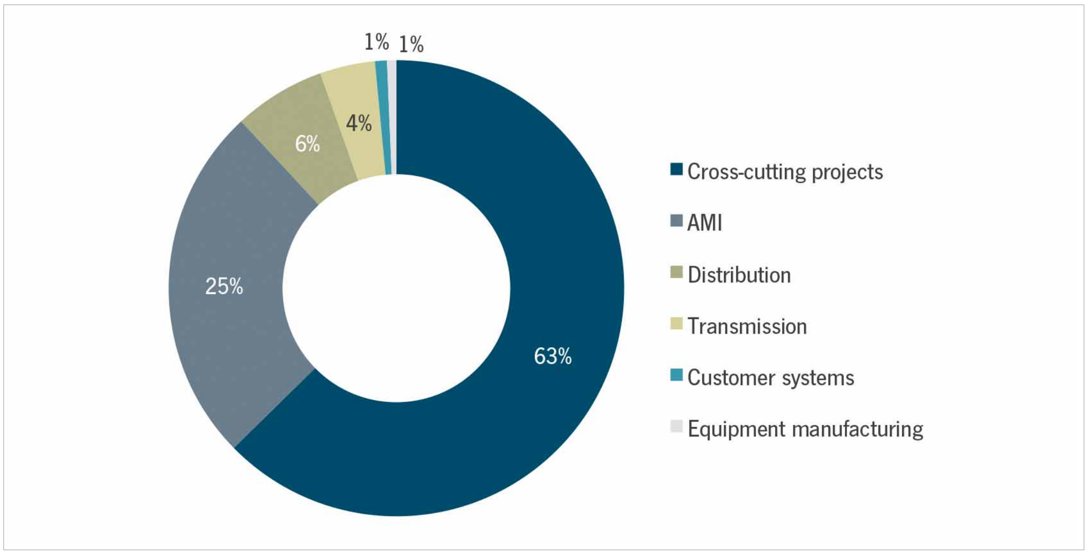
SOURCE: SMARTGRID.GOV

FIGURE 3-9: DISTRIBUTION AUTOMATION EXPENDITURES



SOURCE: GTM RESEARCH

FIGURE 3-10: TOTAL SGIG SPENDING BY TECHNOLOGY



SOURCE: GTM RESEARCH

3.6.3 Trends, Thought Leaders, Vendors, Ideas

Because they are capital-intensive and complex to implement in the field, it has historically been difficult to make a persuasive business case for DA upgrades. From a vendor's perspective, DA is a highly specialized space where margins depend on large-scale production volumes, while technological success is based on the opportunity to cooperate with a utility in order to test and adapt devices to real-world grid conditions. However, because DA technology is merely an improvement of engrained functionalities of the extant power system, DA benefits are more clear-cut within the current system architecture than are the benefits of other technologies, such as those focused on energy efficiency. This has two chief consequences:

- **Automated functionalities achieve benefits without customer intervention.** Technologies such as volt/VAR optimization and automated switching do not hinge on shifts in customer behavior.
- **The benefits are readily recognizable even in the business-as-usual scenario.** DA benefits, such as reduced outage and maintenance costs and prolonged asset life, are easy to recover within the current utility business model. Few other types of savings are as obvious as significantly reducing the number of truck rolls during outages or deferring the cost of buying new power transformers.

From a vendor's perspective, AMI and DA are becoming more entangled due to the increasingly common use of networking infrastructure and shared data usage. The process of establishing networks that are able to accommodate several types of signals with different priorities, such as AMI data and DA signals, is one form of enhanced asset utilization – as well as one of the most significant challenges that lies ahead.

3.6.4 Risk and Opportunity

Major opportunity: Increased visibility of DA benefits, driven by public interest in disaster resiliency and more widespread use of analytics

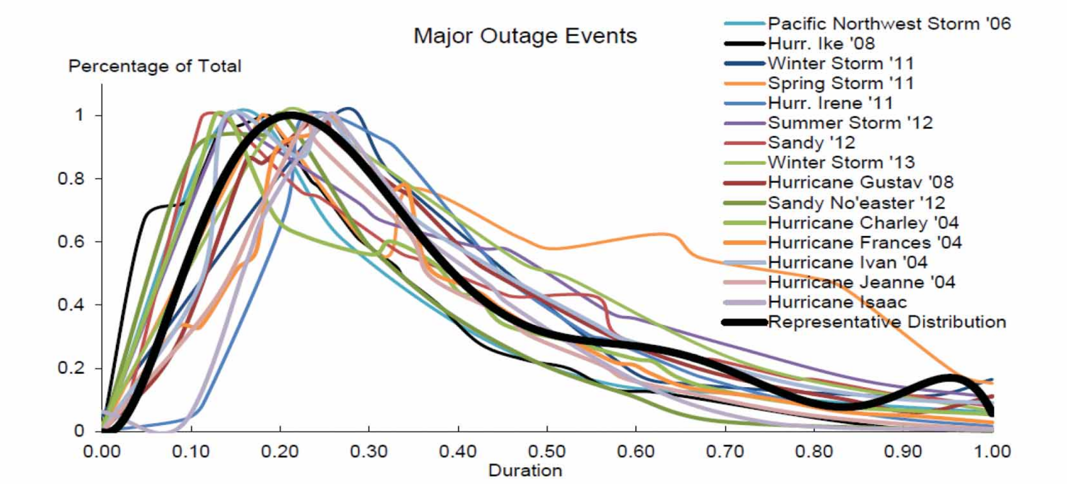
Major risk: Patchwork deployments with large costs and limited benefits due to lack of interoperability

FIGURE 3-11: THE IMPACT OF FAST REACTIONS TO OUTAGES

Why the reaction speeds of utilities determine the ultimate cost of outages

Technologies such as distribution automation, grid optimization and AMI are at the heart of efficient cost avoidance efforts because they influence a decisive parameter of outage cost: power outage duration. As the graph below illustrates, the number of affected customers peaks at about one-fifth of the total outage duration, which can range from minutes to days after the start of the outage.

When calculating the total cost of outages, both frequency and duration play a role. According to a Lawrence Berkeley National Laboratory analysis, 67% of outage costs were caused by interruptions shorter than 5 minutes, because these are more frequent than longer outages [29]. Fast-reacting DA devices will have a major impact on reducing costs because they impact the largest category of outages, and significant cost reductions will occur with widespread adoption of DA.



Source: Department of Energy, Office of Electrcity Delivery and Energy Reliability

SOURCE: DEPARTMENT OF ENERGY, OFFICE OF ELECTRCITY AND ENERGY RELIABILITY

3.7 Energy Storage at the Grid Edge

3.7.1 Framing the Topic

Storage provides stability at the grid edge. It bridges the gap between supply and demand – a gap that can take different forms depending on the location in the network. Gaps between a building's power demand and the output of its rooftop solar system requires local distributed storage, whereas gaps between the desired and actual network frequency require ancillary services provided by storage. Storage is a particularly promising market because its wide range of value propositions is beginning to be translated into business and regulatory concepts.

Energy storage solutions can be separated into the following technology groups:

- Grid-connected energy storage, which are tied specifically to a solar or wind project or are used as an independent generation source/temporary sink
- Distributed storage, combined with distributed generation and designed to time-shift generation and enhance value creation
- Backup storage for emergency startup applications

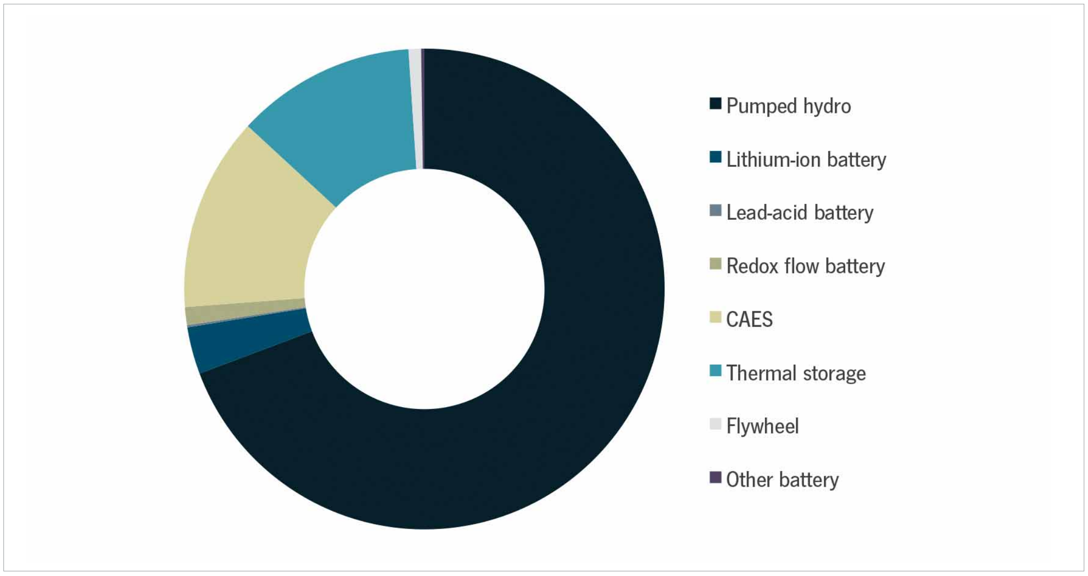
Two recent changes in the market perception of storage are worth highlighting:

1. The discussion has shifted from focusing purely on cost to focusing on the overarching value of storage, and specifically, its locational value.
2. A more differentiated understanding of storage benefits will drive the establishment of a responsive and up-to-date regulatory framework. Storage can do more than supplying power when other sources are unavailable: it can also provide ancillary services or facilitate peak shaving. This will also foster the development of a market framework that allows players to monetize the unique benefits of storage, such as allowing storage providers to bid into the ancillary services market. FERC Order 784, issued in July 2013, eases restrictions on selling ancillary services and ensures that the speed and accuracy of ancillary services are accurately compensated. In light of a recent study by EPRI, this move on FERC's part becomes even more prescient: in a study conducted for the California Public Utilities Commission, the positive net value of storage scenarios was found to be strongly driven by the profit potential of frequency regulation.

3.7.2 Deployment and Growth Projections

According to the DOE Energy Storage database, the U.S. currently has 19.1 GW of rated power capacity in storage under operation [30]. The bulk of the power capacity[5] is pumped hydro, while the remaining 2% is primarily compressed air energy storage (CAES) or battery storage. This is similar to the structure of the worldwide storage landscape. However, the distribution is likely to change in the future as the storage landscape becomes more battery-oriented and distributed. In the group of contracted, announced, and under-construction projects, the share of battery storage increases from 1% to 5%, mainly as a result of lithium-ion battery deployments. Flywheels are at least part of the game, with 1% share of rated power. The large share of thermal storage (12%) is primarily due to the Abengoa concentrating solar power project in Arizona.

FIGURE 3-12: RATED POWER OF FUTURE U.S. STORAGE BY TECHNOLOGY



SOURCE: DOE ENERGY STORAGE DATABASE

Both the preferred technology used and the size of storage projects are in flux. A total of twenty-four of 49 future projects have a rated power of less than 500 kW, compared to roughly one-third of operational projects that fall into this size category. The share of distributed storage will grow as these distributed installations come on-line, many of them in microgrids.

3.7.3 Trends, Thought Leaders, Vendors, Ideas

Accurate compensation for frequency regulation will generate a market pull for fast-responding technologies like batteries and flywheels, but ancillary services will not be sufficient to kick-start the entirety of the storage market. The bottom line is that each storage application has its own value propositions to which grid-edge market environments need to be aligned. The following section identifies a collection of different drivers grouped by storage application type.

Drivers for solar systems with storage in residential applications include:

- Subsidies and finance options tied to PV plus storage, reducing upfront system costs
- High electricity prices making more self-consumption favorable
- Meeting reliability requirements

Drivers for commercial/industrial PV systems with storage include:

- Lowering electricity rates
- Lower peak demand charges
- Access to capacity markets
- Availability of emergency backup power

Drivers for utility-owned storage at the transmission/distribution level include:

- Meeting reliability requirements while constraining upgrade costs caused by distributed renewable energy integration
- Capacity firming
- Congestion relief and deferral of transmission system upgrades
- Disaster resiliency, especially for community energy storage

Drivers for storage in microgrids/off-grid applications include:

- Reducing dependence on backup diesel generators and price uncertainty
- Emergency backup power

Major barriers include:

- Limited possibility of sharing storage profits among different stakeholders. If a utility owns storage and consumers benefit from lower electricity charges due to congestion relief, what is the benefit for utilities?
- Battery prices are still too high to allow for mass-market adoption

The battery market looks like the place to be. CAES and flywheels have been around for years without major innovations or significant price-drops on the horizon, but battery research facilities such as the Argonne National Lab have made major strides. Since the upper bound of lithium-ion battery performance might be reached in the next five years, metal-air batteries or flow batteries appear to have the most potential. However, in order to enable light-duty, long-distance travel in electric vehicles, battery energy density needs to make a dramatic leap forward. Hydrocarbons still store many times more energy per unit of mass than batteries. Lithium-air batteries promise theoretical energy densities close to gasoline, but face major issues around recharging, as do zinc-air batteries. Their key advantage, external oxidation, is also their chief disadvantage: because the air around the battery takes the role of the electrolyte, it is not packed within the device, so energy density increases. But oxidization processes are not easily reversible (which is a necessary condition for recharging), and research could still take years.

The multifaceted benefits of storage have recently turned it into the most attractive smart grid market for investors. A total of 53% of overall deal value was invested in storage in Q2 2013, equating to roughly $180 million. Leading vendors Aquion Energy, Bloom Energy and Eos are focusing on battery and fuel cell technology. Bloom Energy has received a great deal attention due to the $1 billion in venture capital it has raised over its short lifetime of only a decade. The firm appears to have made a compelling case for innovative storage financing and international cooperation, partnering with Japan's SoftBank.

In the long run, meeting the needs of solar integration will be crucial for energy storage vendors. In solar-driven California, the gap between PV power supply at noon at peak consumption in the late afternoon and evening is growing. It is clear why the Public Utilities Commission has joined the most aggressive storage advocates by issuing a proposal to deploy 1.33 GW of energy storage by 2020. One remarkable detail could drive regulatory development forward: participating utilities are given latitude to defer their deployment targets if storage is deemed to not be cost-efficient. The hope is that this will motivate utilities to further quantify the potential benefits of storage.

3.7.4 Risk and Opportunity

Major opportunity: As use cases for different storage technologies materialize, so will business cases.

Major risk: Lack of integrated measures to create market signals appropriate for each specific application of storage

3.8 Electric Vehicles

3.8.1 Framing the Topic

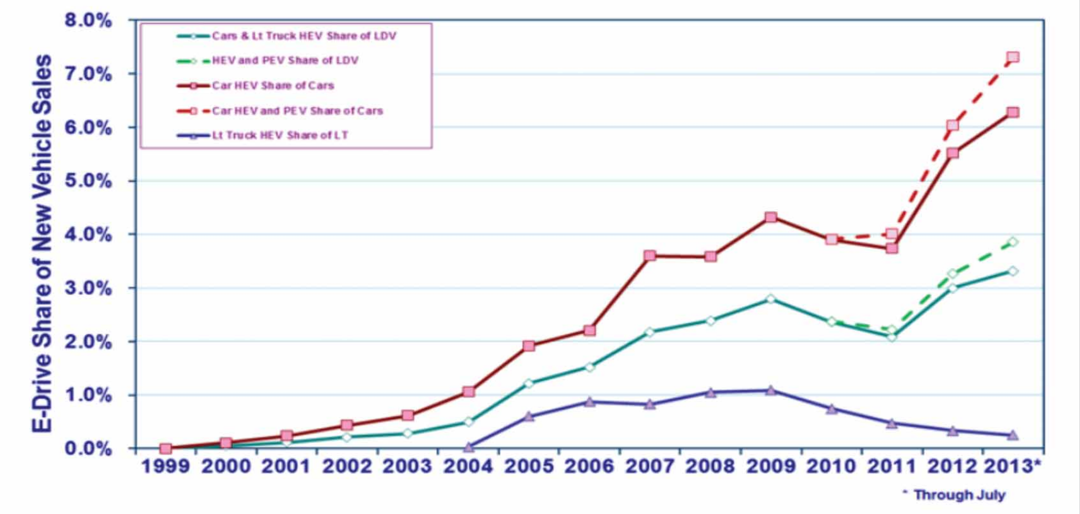
Electric vehicles are the mobile agent of the grid edge. The interest in decoupling transportation from fossil fuel consumption is primarily driven by environmental and economic motives, but grid-edge considerations focus on the system benefits of a large EV fleet. Instead of creating additional peaks by simultaneous charging of large numbers of vehicles, electric cars could make use of excess wind power at night, serve as mobile storage devices, and thus create new revenue streams for car owners. The EV market segment includes plug-in hybrid and electric-only EVs, vehicle-to-grid technologies, and smart charging solutions.

3.8.2 Deployment and Growth Projections

Plug-in electric vehicles sold twice as well in the first half of 2013 than they did in 2012, according to the DOE [31]. This rate of growth in the market appears to be much faster than in the early phase of hybrid vehicles. Many industry observers point to this as a harbinger of massive success to come. However, even if the share of EVs relative to total car sales is increasing rapidly, it is still small, as Fig. 3-12 illustrates.

The market is bound to reach a turning point in the coming decade. Polk Research found that the U.S. car fleet hit a new record age of 11.4 years in 2013, up 16% from 2002 [32]. During the same period of time, fuel efficiencies have risen from a miles-per-gallon perspective, so the gap between old models and newer models with better fuel economy could spur increased demand in the short term. The Rocky Mountain Institute predicts that 50% of all U.S. vehicles will be electrified by 2050 [33].

FIGURE 3-13: EV SHARE OF NEW VEHICLE SALES



SOURCE: ARGONNE NATIONAL LABORATORY

3.8.3 Trends, Thought Leaders, Vendors, Ideas

The EV market mirrors many challenges of the grid edge at a smaller scale. Factors to consider include:

Standardization: Standardization is a major stepping stone on the pathway to a plug-and-play environment of charging stations. In July, the DOE opened a new Electric Vehicle Smart Grid Interoperability Center at Argonne National Laboratories, which will focus on establishing technologies and standards for EV connectivity and equipment compatibility, while cooperating with interoperability efforts undertaken by the EU Commission. The importance of standards is not limited to charging stations: if electric vehicles are to be part of a dynamic grid infrastructure, standardized communication protocols are just as important as OpenADR for demand response, in terms of creating a single language with which EVs and energy service providers can communicate.

New business models: Henry Ford's factories might have given rise to the American dream, but the model of individual car ownership might not be sufficient to reach high EV penetration. New and emerging paradigms include car sharing, battery switching, web-enhanced leasing, and remuneration for power fed back into the grid. So far, no clearly dominant concept has emerged. Better Place's battery-switching concept failed in Israel, mainly because few EV vendors enabled switching.

U.S. efforts around V2G remain rare, but they do exist. In a University of Delaware project, fifteen BMW Mini E cars fed power back into the grid in reaction to a charging signal sent by grid operator PJM Interconnection, earning about $5 a day [34]. Cars need a two-way charger for this; standard models of the Nissan Leaf or Chevrolet Volt currently come without these for pricing reasons. Several car companies are currently working on integrating two-way chargers. With more powerful chargers, EVs could even participate in the market for spinning reserves. Only a couple of years ago, many still deemed V2G too far-fetched to achieve widespread practical application.

Overall, there seems to be a gap between technological advancement and consumer perception. Electric vehicles can compete with internal combustion engine vehicles in terms of acceleration and speed, but "range anxiety" and cost concerns remain. In one recent survey conducted by the European Commission, more than 3,600 interviewees in six countries chose "distance with one charge" and "purchase price" as the top features that would need to be improved in order to compel them to consider an EV purchase, closely followed by the possibility of recharging at home [35].

New metrics for comparison will be a vital part of EV growth in the near future. This is due in large part to the fact that the economics of EVs are considered relative to ICE economics, and as such, having an accurate means of comparison is important. The DOE's eGallon metric is an example of one such new benchmarks. It compares the cost of regular fuel against the cost to fuel an electric vehicle in a particular state. It is an attractive, easy-to-use tool that condenses a complex market into a simplified format for consumers.

3.8.4 Risk and Opportunity

Major Opportunity: Decreasing battery prices make EVs more economical; better comparative tools are created to inform the public.

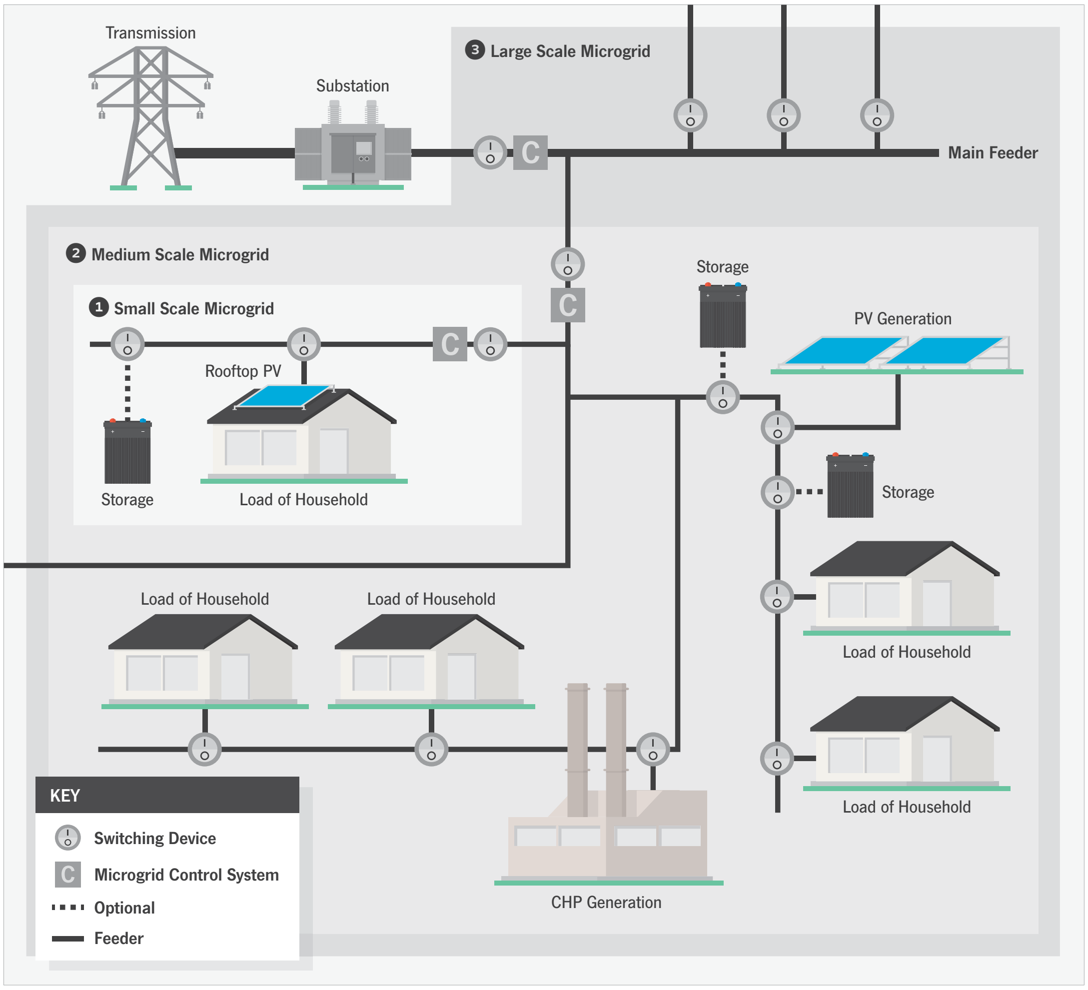
Major risk: The early push for EVs was shaped by an anticipated scarcity of oil, but the U.S. tight oil revolution will reduce the urgency of electrifying transportation.

3.9 Microgrids

3.9.1 Framing the Topic

Microgrids are a mirror of the power grid's macro-structure at micro-scale, typically ranging from between several kilowatts (residential) up to megawatt scale in size. They enlarge features such as distributed generation while compressing others, such as transmission and wide-area balancing. The defining characteristic of a microgrid is the co-location of power generation and load, which are interconnected in a clearly delimited entity that can operate in grid-connected or island mode. The microgrid may or may not include parts of the utility distribution network, but it always presents itself to the grid as controllable load or power source. The following structural diagram illustrates how GTM Research envisions a microgrid.

FIGURE 3-14: CONCEPTUAL REPRESENTATION OF A MICROGRID



SOURCE: GTM RESEARCH, DOE

The precise classification of different types of microgrids remains a challenge, especially when it comes to factors such as islanding capabilities and controls, the number of grid interconnection points, and the ownership of generation and distribution assets. The World Bank's July 2013 energy strategy paper, which omits the term "microgrid" throughout the entirety of its 39-page discussion of distributed energy and "mini-grids," is one example of this conceptual ambiguity [36]. But there are promising developments, as well. Further development of IEEE's standard 1547, the major guideline for distributed resource integration, focuses specifically on microgrid issues such as unintentional islanding and will help streamline implementation strategies.

3.9.2 Deployment Status and Growth Projections

2013 has seen seven announcements of new microgrid projects or add-ons in the U.S., more than ever before. This will add to an estimated 1,500 MW of microgrid capacity that is already operating [37]. In India and other emerging economies, village-level microgrids are becoming a defining pillar of rural electrification projects. However, venture capitalists have not yet embraced the microgrid, most likely because it remains uncertain whether the technology will ever evolve from niche applications and public institutions to the larger market of apartment blocks, hospitals, homes or data centers. Further, there is a possibility that bulk power grid modernization efforts will make islanding capabilities unnecessarily expensive. The answer will likely be decided in a race between macro and micro grid intelligence. If more investments are made in grid hardening and cheaper DG systems, a microgrid might not be economical other than for critical loads. The advantages and disadvantages of different autonomy scenarios are highlighted in the following diagram.

FIGURE 3-15: MICROGRID AUTONOMY SCENARIOS

	HIGH AUTONOMY SCENARIO: MANY ISLANDED MICROGRIDS	MEDIUM AUTONOMY SCENARIO: ONE MACROGRID COMPRISED OF MANY GRID-CONNECTED MICROGRIDS	HIGH DEPENDENCE SCENARIO: WIDE-AREA CONNECTIVITY WITH FEW MICROGRIDS
Advantages	High cybersecurity of “sealed islands”; high local energy efficiency; ability to optimize local solutions for specific targets, such as emissions reduction or deferring local network upgrades	Efficient wide-area balancing (DG systems become controllable, virtual power plants); reduced transmission losses; peak demand reduction at distribution feeder	Wide-area balancing allows leveraging advantages of specific geographies
Disadvantages	High cost of stability management; utility resistance due to complete customer loss in traditional markets; limited balancing capabilities, potential technical difficulties for transient state control of many parallel microgrids	Sunk investment when islanding capabilities are not used most of the time	High fragility of transmission lines; high susceptibility to cyber-attacks; transmission losses
Drivers	High electricity prices that encourage “going offline”; density of critical loads; cost reductions based on fast development of standardized microgrid building blocks	Regulatory and legal standards for microgrid implementation and value stream recovery, limited progress in islanding control	Slow regulatory progress; large-scale transmission system investments
Grid-Edge Relevance	Medium	High	Low

SOURCE: GTM RESEARCH

3.9.3 Trends, Thought Leaders, Vendors, Ideas

Slowly but steadily, the microgrid market is progressing from the demonstration phase to the deployment phase, at least in public institutions. Among the most important milestones to date are the 50% reduction in peak load consumption achieved by the Illinois Institute of Technology microgrid project [38], the 25 military microgrid installations across the U.S., and the Food and Drug Administration's cogeneration-based microgrid in Maryland being able to maintain power during Hurricane Sandy.

The U.S. military currently takes an important role as an early adopter and a provider of conceptual tools. Energy Surety Microgrids (ESM), a design methodology developed in cooperation with Sandia National Laboratories, helps providing a blueprint for microgrids that is adapted to specific local system needs. Civilian applications are under way: ESM is currently used to help develop a microgrid for New Jersey's Northeast corridor transit system.

From a vendor's perspective, microgrids hold the most obvious promise for energy storage companies. The term "microgrid" is not always linked with intermittent energy sources; in fact, many projects in operation use combined heat and power. However, they do almost always need some form of storage mechanism for self-maintenance or time-shifting. The use of Primus' flow batteries at the Marine Corps Air Station in Miramar, California is one recent example of the storage market potential of microgrids. Likewise, microgrids could be helpful for analytics firms and for large incumbents like Lockheed Martin and Boeing that leverage competence from military and aircraft technology. After all, every plane already has its own small microgrid; the technology just needs to make a safe landing on civilian grounds, so to speak.

3.9.4 Risk and Opportunity

Major opportunity: Combinations of standardization and customization to local needs, allowing the optimization of local consumption patterns based on a specific customer's objective

Major risk: Microgrids could remain undefined as a legal entity. Uncertainties around value streams will impede private capital investment because addressing a different regulatory environment for every installation makes project development a complicated and costly process.

3.10 Home and Building Energy Management Systems

3.10.1 Framing the Topic

Home and building energy management systems (HEMS/BEMS) represent the grid edge at the most granular level visible to the consumer. Monitoring different loads and generators is one aspect, along with presenting this information in a standardized fashion to the outside network and to the users in the home or building in question. To the outside, HEM systems facilitate communication with utilities and providers of demand response signals. Inside, they are the key to enhanced consumer awareness and automated energy efficiency via control of heaters, coolers and other appliances.

This market segment includes home and building area networks (HAN/BAN), visualization software/hardware (displays, smartphone applications), smart thermostats, and web applications/portals.

3.10.2 Deployment and Growth Projections

Smart thermostat vendors like Nest, Honeywell, and Tado have helped the HEM market maintain momentum in recent years, but penetration is still below 2% in most states. In part, growth is impeded by a lack of clarity about the ultimate destination of HEM development. How much impact will the customer's use of energy management really have before automation catches up?

There is one development that is likely to push the market forward. The growth of residential PV will increase HEMS interest among homeowners, because data collection about consumption patterns will allow for the optimization of individual systems. Overall, GTM Research estimates that annual spending in the HEMS market already exceeds $1 billion and is likely to grow further. With a 1% adoption rate among 115 million households with an investment in the region of $300 per system, cumulative spending could easily reach $350 million, which doesn't include matching investments, such as communication infrastructure.

For energy efficiency, HEMS and BEMS play a crucial role due simply to the large share of buildings that contribute to overall energy consumption in the U.S. According to the DOE's Buildings Energy Data Book, U.S. commercial and residential buildings consume 41% of total primary energy and account for roughly one-third of greenhouse gas emissions [39, 40].

For the HEM market to advance, it must overcome the following obstacles:

- The current market is characterized by a plethora of vendors and different solutions with sometimes overlapping functionalities
- The high upfront cost of devices, which often exceed $200
- Lack of utility and vendor cooperation

These obstacles should be overcome as soon as possible, as overall grid-edge functionality is dependent on HEM and BEM to transform buildings and homes into reliable players in the DR and ancillary services markets. Drivers of this development are:

- Dynamic pricing
- The trend of commercial buildings owners and operators exhibiting intense interest in cost savings stemming from energy efficiency

3.10.3 Trends, Thought Leaders, Vendors, Ideas

Two major trends will shape the near-term market outlook for HEMS/BEMS:

- **Creativity around new sales strategies:** Finding new gateways into homes and buildings will be the next step in the business evolution of the HEMS market. Sunrun's partnership with Nest, whereby buyers of a PV system receive a complimentary thermostat for free, is one example for tapping into a market of environmentally conscious customers. Another example is linking HEMS with smartphone applications, as energy management activities conducted via smartphone circumvent the need for costly in-home displays, and consumers do not have to take the time to become accustomed to an unfamiliar device.
- **Emergence of cloud-based BEMS:** The emergence of cloud-based BEMS solutions, where local nodes input data in server-hosted applications, will make installation procedures easier, as hardware and software will not have to be selected for each building. Many industry observers have flagged the common usage of a single host server as a security concern, so cybersecurity issues will need to be resolved before widespread application will become realistic.

3.10.4 Risk and Opportunity

Major opportunity: Attractive thermostats may stimulate interest in home and building energy management

Major risk: There is little marketing of building energy management systems, so building operators might not be well informed about available systems and their value.

End Notes

4. About three quarters of U.S. customers are served by investor owned utilities.
5. This is the power that can be supplied instantly by the storage device, while energy capacity (expressed in MWh) pertains to the duration of the available power supply.

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