Smart Grid – Technology Innovation Group Report

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Tokyo, Japan
Smart Grid Technology Innovation Group Report was developed at the request of the e8 Leadership team. Scope of work assigned to the group developing the report was to examine member company experiences in Smart Grid deployment and develop recommendations that could help accelerate the deployment of Smart Grid across e8 members and the world in general. The group evaluated regulatory, financial, technical, policy and public communication/education issues that can accelerate or inhibit deployment of smart grid. We attempt to share participant company experiences and challenges in a succinct fashion in this report.

Participating e8 members:
- American Electric Power
- Duke Energy
- Electricite de France (EDF)
- Ente Nazionale per l'Energia eLettrica (Enel)
- Hydro-Quebec
- Kansai Electric Power Company
- RWE AG
- Tokyo Electric Power Company

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INTRODUCTION

Ancient peoples knew of strange phenomena involving amber (“Elektra” in ancient Greek) and lodestones, phenomena we call electricity and magnetism. By the mid-1800s, electrical pioneers such as Andre Ampere, Allessandro Volta, and Georg Ohm had provided the scientific knowledge concerning electrical phenomena that made the first efforts at large-scale electrical generation possible in the 1880s and 1890s. Since those first developments of practical electrical power generation and distribution, the alternating current (AC) electrical generation and distribution system as it exists today has evolved from separate and disconnected entities to a vast interconnected system of power providers and users. While electricity primarily powered electric lighting in the beginning, today a seemingly limitless array of machinery and appliances operate using grid-supplied voltage and current.

Throughout the world, people in developed nations such as the e8 benefit from economical electricity. However, while those entities that generate and transmit electrical energy strive to become ever more efficient and pollute less, the sheer scale of electrical demand – one that continues to grow each year despite current economic strains – would be expected to cause increasing pollution and put an increasing strain on the electrical system meant to accommodate that demand. In some, but not all parts of the world, fixed electric rates enjoyed by the residential population – regardless of the actual cost of generation at time of day – contribute to ever larger peak and extreme peak loads and may serve to exacerbate the need for new construction.

A balancing act ensues with many actors – electricity providers, regulatory bodies and users – pulling and pushing according to their view of the situation, one that differs by region. On the one hand, electricity providers see the need for more generating capacity while regulatory bodies may not want the rise in rates that the new construction would require. All the while, the people using the electricity may not be aware of their own role in the balancing act. In many parts of the world, these people have never before had to be concerned with their electric consumption.

Fortunately, advances in computer controls, communications, alternative energy and other components have enabled a method of using the existing transmission and distribution structure to provide power more efficiently throughout the day. This method may also result in less pollution through the integration of cleaner distributed resources, and, through two-way communication with customers, may help moderate electrical demand at critical points during the day or night, beyond the capabilities of the transmission system alone. This is known as the Smart Grid.
Current State of the Electrical Grid vs. the Smart Grid

After a hundred years or so, the state of electrical generation and distribution in developed nations is considered mature. In the United States, for instance, the electrical grid infrastructure, representing more than $1 trillion in asset value, consists around 450,000 miles of transmission, 5 million miles of distribution and 22,000 substations and serving well over 100 million customers and at least 283 million people. Meanwhile, Canadian utilities invested $2.4 billion in 2007 in high-voltage transmission infrastructure numbering over 45,000 miles and $1.7 billion in distribution infrastructure. An electric utility company may monitor and control hundreds of grid devices as they operate their part of the grid. Investments in generation, transmission and distribution for developed regions have largely been made with maintenance or replacement of same being the greater concern. Figure 1-1 illustrates the basic structure of the current grid for typical voltages in the United States operating at 60Hz.

![Figure 1-1 Basic Structure of Electrical Generation and Distribution [1]](image)

In Europe, a system of interconnected Transmission System Operators (TSOs) organized as the European Network of Transmission System Operators for Electricity (ENTSO-E – formerly UCTE – Union for the Coordination of Electricity Transmission). This organization in the EU spans 34 countries with 42 TSOs sharing a synchronous transmission grid [2]. Figure 1-2 shows the extent of ENTSO-E in Western Europe, which is completely interconnected and operating at 50Hz, although specific voltage levels will differ for some European nations. Figure 1-3 illustrates transmission and distribution voltages typical for Germany.
Figure 1-2
Detail of ENTSO-E Map Showing Western Europe [3]
While the Smart Grid will build upon the current electrical transmission and distribution systems, it will have features essential to its operation that will involve telecommunication and monitoring systems to enable two-way communication and interoperability, as well as the optimal integration of distributed energy resources (DER) including storage. Thus, with Smart Grid capabilities, the current framework shown in Figure 1-3 will more resemble that shown in Figure 1-4.
With the exception of large-scale energy storage, most of what is pictured in the previous figure exists in some regions of Europe. The main difference will be that instead of merely being connected to the grid, all components will be integrated. In essence, rather than simply being a passive collection of parts associated with power generation and distribution, the Smart Grid will be an active system engaged in optimizing itself. [6]

The island nation of Japan has a grid system operating at 50Hz on the eastern regions of the island while the western regions operate at 60Hz. Transmission-level voltages may be seen in Figure 1-5.
WHAT IS A SMART GRID?

The state of the current electric power delivery system as compared to the Smart Grid may be compared to today’s winged aircraft: the basic design of the airplane is the same as forty years ago, yet, to be operated, modern aircraft must have very sophisticated controls and sensors. The Smart Grid will use the basic design of the electrical system in use today – probably the same major components that exist in the field today; however, the Smart Grid must have many more monitors, sensors, switching devices and sophisticated communications that will allow it to be a highly automated power delivery system.

The electrical grid of today and for the last hundred years or so has consisted of centralized generation, transmission and distribution. As shown earlier in Figure 1-1, electrical generation has consisted of one or more large sources of power at a given voltage, stepped up to a much higher voltage level for transmission, and then stepped down for distribution to all end-users, essentially flowing one way from the beginning to the last load in the circuit. Figures 2-1 and 2-2 illustrate the interconnected electric grids spanning North America, Europe and Western Asia. While modern electrical generation
and distribution technology is well-established and mature, many constraints, mandates, developments, and demands in the modern world now push power providers in a new direction.

Figure 2-1
Interconnections of North America [8]
The Smart Grid, rather than the top-down relationship indicated by Figure 1-1, may be considered an interconnected set of domains as in Figure 2-3, consisting of various actors with similar objectives. The actors in each domain may be organizations, devices, computer system or software applications that make decisions and exchange information. Each domain will have secure communications connections with the other actors, whereas the electrical connections will be between Bulk Generation, Transmission, Distribution and Customer as with the current framework – the main difference being that the customer may also be an electrical supplier. [10]
In the United States, The American Recovery and Reinvestment Act of 2009 (also known as the federal stimulus program) in response to the recent world-wide economic downturn has targeted Smart Grid development. Figure 2-4 illustrates the breakdown of projects targeted by this funding. “Integrated systems” in the figure refers to “Integrating and Crosscutting across Different ‘Smart’ Components of a Smart Grid” according to information on the Web site.
At the present time, the various components for the Smart Grid continue to develop globally without a definite destination or even definition of what this new direction will become. One common component, the Smart Meter, for instance, may be considered a necessary part of a Smart Grid; however, meter deployments alone will not fulfill its vision. This report, in part, seeks to provide a reasonably accurate definition as well as a destination along with suggestions concerning a path that members may use to achieve a Smart Grid.

The Smart Grid: A Definition

The Smart Grid will be a customer-centered, interactive, reliable, flexible, optimal, economical, economically responsive and, ultimately, a sustainable and environmentally responsible electrical power generation and distribution system. Electric utilities must play a key role in its development.

Customer-centered: The customer may determine – using real-time or near real-time information as to cost of generation, as well as cost to the environment at time of use – his or her most economical and/or most environmentally-friendly use of energy. By enabling the implementation of enhanced dynamic pricing and the use of advanced IT, the Smart Grid will empower the customer by providing him real-time price signals, while optimizing costs for the utilities. At the same time, the Smart Grid will enable the customer to become an electricity producer as well, and thus have the opportunity to be rewarded for electricity generated and admitted into the system.
Note: The customer-centered definition may not cover all countries/companies. For example, the time of use (TOU) works very well in Japan; the system divides 24 hours into several segments with each segment having a different price menu, which brings huge benefits to both customers and power suppliers as well.

Interactive: An intelligent system with two-way communication in real time between utilities, generation systems, transmission systems, distribution systems and customer/end users concerning the state of the power systems, cost of generation and cost of consumption at time of day.

Reliable: With more monitoring devices as well as automation control of the transmission and distribution grid, a far greater capability of both responding to and adjusting grid conditions in real time will become possible. This will yield a more robust, reliable and secure system.

Flexible: Power may come from a variety of sources in different geographic locations including large-scale and small-scale new renewable power sources as well as conventional generating sources.

Optimal: The Smart Grid will allow for the implementation of demand-response programs that will improve matching of load and power supply at any point in time at least cost, thus optimizing the use of available energy resources. This will also reduce the need for capital investment in constructing excess expensive peak-load capacity.

Economical: Improved operational efficiency, reliability and sustainability will allow the cost of generation and distribution to be kept as low as possible so that the cost to the customer and effects on the environment may also be kept low.

Economically responsive: At any time, relying on the best allocation of resources and merit order of generation capacities, the Smart Grid will enable the utility and customers to improve cost efficiency by using detailed information and data. This data will determine the right price signal and thus will keep the cost of energy generation and use as low as possible, to enable the use of decentralized storage when competitive, decentralized renewable generation if available, and thus, by enabling the ‘smart use’ of energy. As a result, the need for expensive peak or extreme peak generation will eventually be minimized if not eliminated.

Sustainable: By both reducing the need for building more generating capacity and reducing adverse affects on the environment, the Smart Grid may conserve money and resources, and will, through what may be termed the ‘smart use’ of electricity, continue to provide adequate electrical power into the future. Moreover, the Smart Grid will foster innovation - allowing new markets and opportunities not possible with the traditional grid.

Environmentally responsible: With its ability to connect sources of energy both locally and from different geographic locations that release fewer or no pollutants into the air or water, the Smart Grid will enable customers to choose cleaner sources of energy. Thus, the need to use those sources of energy that produce more pollution will be minimized. In this way, the Smart Grid has the potential to become the basis for a world-wide, low carbon society.
Through its flexibility – over and above most existing generation and transmission infrastructures today – the Smart Grid makes possible all the objectives above. Moreover, utilities in all parts of the world may pursue all or select only those objectives that relate specifically to their own business objectives and situation whether regulatory, political, economic, or environmental. The Smart Grid will be capable as well of accommodating new and existing technologies.

In the pursuit of a more efficient and economical distribution grid, one possible outcome of Smart Grid developments may be that individual customers will use less power or they may use more of less expensively generated power. These changes in consumption patterns may require new or modified business models for utilities. The question emerges: Why should power providers choose to spend money to sell less power? In the future, individual users are likely to use less power through more efficient appliances; however, the Smart Grid will enable many more uses for electricity – e.g. for industry and domestic uses such as electric vehicles – such that power providers will very likely sell more power.

**Drivers to Adopt the Smart Grid**

The answer to the previous question involves several factors already mentioned – in particular, in developed and developing areas worldwide, electrical power generation is expected to increase over time. The Energy Information Agency (EIA), offers worldwide energy statistics divided into those countries in the Organization for Economic Cooperation and Development (OECD) and those not in that organization (non-OECD). Information from the EIA shown in Figure 2-5 illustrates this expected increase – less dramatic for nations in the OECD but far more dramatic for non-OECD nations. The recent economic conditions in countries such as the United States, for instance, have made for a smaller yearly power generation increase than in previous years according to EIA statistics. It may be seen as well that much of this increased generation, typically baseline, is expected to come from burning coal. The greenhouse gas effect expected from the carbon dioxide (CO2) released by using coal as a fuel concerns many nations around the globe.

One of the most serious conditions for power providers is electrical usage at times of peak and extreme peak loads. This type of generation must start quickly when needed and may only be needed for a short period of time. Typically, these facilities use more expensive fuel.
Eventually, the increasing load will necessitate new and ever more expensive generation to handle the increase as well as upgrades in infrastructure to carry the load. All of these efforts, if allowed by regulators, would likely result in increased usage rates (called tariffs) charged to customers. However, regulators or policymakers tend to be wary of allowing such increases. Meanwhile, pollution from centralized generation facilities will steadily increase from all but nuclear and hydro; both may be limited by public sentiment or geography – the NIMBY syndrome can sometimes occur as a hindrance to the building of new centralized facilities while most suitable rivers in many developed nations may already have been utilized for hydroelectric generation (although upgrades to existing facilities continue to increase capacity). Coal-fired facilities, then, tend to be the least expensive and most expedient new, large-scale source of electricity to construct. Even so, the public in those regions may oppose any construction of new, central generation facilities – especially those that contribute CO₂, SO₂ and other pollutants to the air and ash waste to the land.

Less-polluting sources of generation developed over the years, known as renewable energy resources, include technologies that use wind and tides, the sun, geothermal and other sources. According to Figure 2-4, the use of these technologies may be expected to increase also. However, these renewable resources are variable to such an extent that power providers may not, as a matter of course, rely on them and yet may in some regions be required by law to accept output from these sources. Another promising source of clean generation that emerged from programs in Space Exploration is the fuel cell. Unfortunately, while producing practically no pollutants (assuming hydrogen as the fuel) and a steady output, the sheer cost of this application along with problematic technical issues make it impractical at the present time for large-scale implementation.

In many developed regions, mounting concern for the effects on the environment from all sources of pollution has made a priority of cutting pollution and CO₂ emissions.
specifically – particularly in Europe where all EU member states have a mandate to do so.

In 2007, the Electric Power Research Institute (EPRI) outlined a plan for reducing CO₂ emissions in the United States from electrical generation that became known as the Prism, shown in Figure 2-6. Extrapolating from those 2007 levels, CO₂ emissions are expected to increase significantly due in part to increased generation of electrical power. However, by increasing efficiency, using many less-polluting technologies that already exist, and upgrading existing facilities, CO₂ emissions from electrical generation may be reduced well below current levels by 2030. The goals of greater efficiency and reduced production of pollutants and CO₂ may be facilitated by the Smart Grid. Indeed, the Smart Grid may foster the ‘smart use’ of electricity such that electricity may replace fossil fuels entirely in many residential, transportation and industrial applications. In this way, ‘smart use’ of electricity may become the basis for a low-carbon society.

The advent of vehicles using electricity rather than petroleum will raise new challenges for utilities and customers alike: drivers cannot simply fill up a tank to operate the vehicles and large numbers of electric vehicles charging from homes or workplaces will add entirely new loads to the grid. Slow-charging operations performed overnight may present a lesser challenge to the grid compared to fast-charging techniques executed randomly during the day. At the same time, large numbers of electric vehicles connected to the grid offer a possible source of power for the system if needed. The Smart Grid,
controlling the process of “Smart Charging” may be the best way to integrate electric vehicles – both as load and as source – into the electric distribution system.

To address these and other conditions and concerns, the Smart Grid offers an effective means of empowering customers, improving system performance, and improving system power flow and energy.

**Leading the world to a low carbon society**

Using the Smart Grid, electric utilities may contribute to building a low-carbon society by taking action on both the supply and demand sides, and coordinating policies and technologies.

On the supply side, this would involve shifting to zero-emission power sources in the long term (i.e.; Nuclear, Renewable, etc.), introducing energy-efficient technologies, reducing transmission loss, and so forth.

According to the International Energy Agency (IEA), 19,854,871 gigawatt hours (GWh) of electricity were produced in 2007 while just over 13 million terajoules (TJ) of heat were obtained through the burning of coal, oil, gas, and biomass – processes that release toxic pollutants as well as CO₂ [15]. These statistics hold a significant opportunity for the Smart Grid. As illustrated in Figure 2-7, on the demand side, utilities may encourage the use of energy-efficient equipment such as heat pumps over resistive technologies for heating and cooling residences and buildings – the “Smart Use of Electricity” – to save primary energy. Electricity may replace the combustion of fossil fuels for transportation and heat generation with greater efficiency – a cross-sector feature – and thus reduce CO₂ emissions. In the case of a restaurant, a completely electrified kitchen will require a much smaller sized air-conditioning or ventilation system since the electric appliances, producing no hot exhaust gases, will require less volume for ventilation. Cost reduction, conservation of primary energy, and reduced CO₂ emissions may thus be achieved. This one example shows how shifting to electricity may have a variety of favorable results.

Therefore, not only is it desirable but also practical and effective to seek a low carbon society through electricity-based technologies on both the supply and demand sides. To ensure the integration of more renewable energies, and to promote the smart use of electricity, the platform required to connect both suppliers and customers is the Smart Grid, forming the basis of a future low-carbon community.
Empowering the Customer

The Smart Grid may offer the customer the choice of paying for less-polluting power sources such as wind, solar, etc. described earlier. Furthermore, the Smart Grid may be used to interact directly with appliances now being developed that will allow customers to monitor their energy usage and to turn them on or off remotely using wireless technologies. In a similar manner, then, utilities could turn such loads off during times of peak loading, or communicate the real price for the energy to the customer that the appliances will use so that the customer may choose to allow those appliances to run or not at that time.

Improving System/Network Performance

Reliability

In his testimony before the United States Congress, on May 5th, 2007, Mr. BirnBaum of CURRENT, LLC indicated that “…existing grids are one-way systems for the delivery of electricity without the self-healing, monitoring and diagnostic capabilities essential to meet demand growth and new security challenges facing us today.” Further, he described the blackout of the previous year in Queens, New York that left 100,000 customers without electrical power for several days while the utility, using the standard outage detection methods used at the time, diagnosed and responded to the outage. The extent of the blackout was astounding: 40 million customers affected in eight states with an estimated financial loss of $6 billion [17].

Other blackouts have occurred worldwide: Western Europe on November 4, 2006, where five million people were without power for 30 minutes, Greece on July 12, 2004, Italy on September 28, 2003, affecting 57 million people, and Australia on March 14, 2005, among others. The interconnected nature of the European grid heightens the possibility that an overload or outage in one country will have severe effects in neighboring countries – the aforementioned outage in Italy originated from a transmission line in
Switzerland that had come in contact with a tree (It should also be noted that these interconnections allow for a quick recovery as well) [18].

At times of peak load when utilities must decide whether or not to start up peak generation facilities or more drastically, to shed loads, the residential customer may be alerted to this situation through the Smart Grid and may respond by choosing either to pay for the more expensive power anyway, or to turn off those appliances that use large amounts of power until later – perhaps allowing the utility not to require the more expensive energy in the first instance, or to prevent overload conditions in the second instance. An overloaded system can become unstable to the point of complete loss of power or blackout lasting perhaps hours or even days at the present time.

Through Distribution Automation, the Smart Grid will also allow automatic reconfiguration of systems where a short-circuit condition or “line fault” has occurred. Called “self-healing,” grid devices activate to isolate the area(s) directly affected by the fault and thus maintain power distribution to adjacent circuits. Where line accidents have caused loss of power, utility crews may respond quickly to the exact location of such outages. Further, the utility crews would know from line instrumentation that power has been either lost or restored to an area rather than having to drive through neighborhoods or the rural countryside either to identify where damage has occurred and power lost or to confirm that power has been restored to those locations. Hydro-Quebec and EPRI have developed precise distribution fault location systems based on wave shape analysis that could serve in this way as Smart Grid applications. ENEL uses fault detectors in its medium and low voltage substations and is investigating, as are other utilities, the use of Smart Meter information for this purpose

**Power Quality**

Utilities must conform to standards regarding harmonic distortion, over- and undervoltage and other factors. However, “power quality” represents a problem over and above network harmonics and voltage level. It remains a problem largely for the customer at the present time. Utility line operations, for instance, that switch various loads or customers that operate large motor loads at random intervals may produce power quality variations in the distribution system that upset sensitive industrial devices or equipment. In many areas currently, the industrial customer – sometimes with the help of the utility – must solve these power quality problems. The Smart Grid may allow active power quality improvement through customer services that offer real-time power quality monitoring and remediation of variations such as momentary outages and voltage dips.

**Improving System Power Flow and Energy**

Losses in the power system due to line and equipment resistance reduce system efficiency. These losses result in part from additional load current needed to supply reactive power (VARs) as illustrated in Figure 2-8 using the Power Triangle. Typically, inductive VARs – the vertical line of the triangle – are due to the magnetizing current required for inductive loads to operate multiplied by the voltage across the load (i.e., volt-ampere reactive or VAR). To supply the real power (Watts) that produces the actual work associated with a load (e.g. heat), the utility must also transmit extra current to supply the VARs. This extra current produces additional losses that are a function of resistance
times the square of the total current, or $I^2R$. In the figure, the angle of $VA$ with respect to $W$ is known as the power angle; the cosine of the power angle is the power factor. As the power angle decreases (green line), the power factor more closely approaches the value of 1.0, the cosine of 0°. At unity power factor, $VA$ and $W$ are equal – the ideal condition at which point no VARs are present. The quantity of watts will not change (assuming the same load) as the power angle changes. The value of VARs and $VA$ will change – both increasing with the increasing power angle (decreasing power factor).

The figure also indicates that capacitive VARs counteract inductive VARs; therefore, the power angle may be reduced and the power factor may be increased (approaching 1.0) by connecting capacitors to the power system. In this way, line current may be reduced, line voltage may be reduced and system efficiency may be increased – less power need be transmitted to support the same load. While utilities have long employed line capacitors with discrete controls (e.g. time clock) to accomplish this task, the Smart Grid, using Volt and VAR optimization (VVO), could respond in real time to power factor conditions and changes thus keeping the system voltage as low as possible and the grid as efficient as possible. In addition, reducing the voltage supplied to the load (end-use customer) has

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Figure 2-8
The Power Triangle [19]

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been shown to also reduce the end-use energy consumption (kWh). In a carbon market, each kWh saved may have a monetary value.

**In Summary**

These drivers for the adoption of the Smart Grid may thus be summarized:

- **Empowering the customer**
  - Through price signals and through technology (Integration of electric storage, e.g. through electric vehicles)
  - The ability to integrate Distributed Energy Resources effectively
  - The capability of adjusting end-use load to match the available supply in near real time (e.g. through dynamic pricing signals and/or direct load control)

- **Improving system performance**
  - Reliability through automatic reconfiguration, or “self-healing”
  - Power Quality improvement through better understanding and control of the operating power system

- **Improving system power flow and energy**
  - The ability to respond in real time to changes in load or line condition to improve efficiency and reduce losses

- **For carbon markets, the Smart Grid may also enable reduction of CO2 emissions through improved efficiency and enhanced integration of intermittent DERs**

- **Resource constraints**
  - Finding sites for central generation facilities

- **Global Climate Change**

The Smart Distribution System described above is a continuity of what utilities have been doing for several decades (improving performance and power flow) by applying new computerized and telecommunications technologies and developing modern applications to increase performance and power flow. These applications represent challenges that depend on each utility’s context (customer satisfaction on reliability and PQ, legacy systems, geographical situation for telecommunication access, etc.).

**Barriers to Adoption of the Smart Grid**

Implementing the Smart Grid will involve new investments in various components and technologies that will enable real-time communication and control at multiple points of the grid. Some existing equipment that functioned adequately in the old grid may not fulfill the demands of the Smart Grid making premature replacement necessary. Regulatory agencies in various regions may not have experience with the Smart Grid concept or understand its potential and therefore may be reluctant to allow its adoption.
Consequently, without buy-in from these agencies, utilities may be reluctant to proceed with Smart Grid initiatives on their own as they may not be allowed to recover their new investments or those previous investments in existing equipment rendered obsolete by the Smart Grid.

Although companies currently design equipment for the future Smart Grid, no standards exist to guide the development of such devices. This absence of a generally-accepted standard may prove to be a barrier.

The Smart Grid will greatly change the way many residential customers have always used electrical power as they would have to consider the actual cost that power at TOU. These customers may prefer the convenience of the old way, to keep to the way things have always been done – especially if, compared to the old way, the new way has the potential to cost them more money should they lose track of their energy usage. To use the telecommunication industry as an example, many customers have discovered to their shocked surprise and consternation that a family member using their chosen cell phone plan (one of many confusing plans) has, through texting, internet access or some other function accomplished using the cell phone, caused a month’s charge to number in extra hundreds or even thousands of dollars!

The access to and information available from customers through the telecommunications technologies that will be used will also cause concern for data privacy and cyber security.

The technologies required to realize the Smart Grid in all of its functionality may not yet exist along with the skilled workforce to implement and maintain it.

These barriers to the adoption of the Smart Grid may thus be summarized:

- Regulatory uncertainty
- Economic disincentives
- Reluctance to change the existing system
- Data privacy and cyber security
- Available technology and required skills
ACHIEVING A SMART GRID

The Smart Grid may be envisioned as a complex, interconnected set of power sources and users with the potential for two-way communication and interoperability. Figures 3-1 and 3-2 illustrate this idea. Many new technologies, devices and systems will be required to build the Smart Grid of the 21st century.

Figure 3-1
A Smart Grid Concept [20]
Applicable Components

The physical components of the Smart Grid may fall generally into two categories seen earlier: those that empower the customer and those that improve system performance and power flow:

- Empowering the customer
  - Meter technologies
  - Telecommunications technologies
  - Demand-side technologies (including hyper-efficient appliances and home automation)
  - Distributed energy resources (DER)
- Improving system performance and power flow
  - Telecommunications technologies
  - Grid Intelligence and Tools
    - System monitoring
    - Data management system
  - Energy efficiency tools
Predictive tools coordinated between generation, transmission, distribution and the customer side

For customers as well as utilities, the Smart Grid, through the above components, will provide better information on consumption, will allow tailored tariffs, increased quality of supply and service, and increased customer choice. For the network operator, the Smart Grid will allow savings in operating cost, increased lifespan of existing infrastructure, and greater customer satisfaction. For the electric power system as a whole, the Smart Grid will enable greater energy efficiency, demand management, peak shaving, increased DER capacity and integration, increased EV hosting capacity and CO₂ reduction.

Although the Smart Grid does not yet exist as such, certain aspects of what will become the Smart Grid appear in some e8 countries already. Moreover, specific devices or techniques may already exist commercially and/or may be part of pilot projects currently underway in various geographic regions. A description of these technologies follows.

**Meter Technology**

Advanced Metering Infrastructure (AMI) offers definite advantages and opportunities over the conventional power meters currently in use around the world. With the old-style non-communicating meters, a person must travel to every meter location (in some areas, inside the residence), then translate and manually record the information registered on the meter dials. AMI devices, however, may be read remotely – perhaps using wireless technology, perhaps using dedicated communication lines or a combination of both. Thus, tremendous savings in labor may be achieved with this technology alone. Because manual meter reading increases the likelihood of misreading, AMI devices will ensure accuracy as well. The addition of two-way communication through the Smart Meter enables real-time transfer of information such as price signals, thus enabling the customer to adjust energy usage accordingly. AMI technologies already exist; e8 members already using them seem satisfied with the results.

**Telecommunications Technologies**

**Utility Operations**

More advanced communication for utility operations combined with sensors will allow for better operation and maintenance of distribution networks as well as quick identification of outage location and repair. These sensors will serve to monitor for power quality variations as well.

**Utility to Consumer**

Advanced communication will allow for the remote reading of meters thus allowing more accurate and dependable billing. Where this has been applied, e8 members report considerable savings over manual reading.

**Consumer Operations**
Advanced communications will enable users of electricity to manage their own consumption day by day – perhaps even in increments of hours or minutes – rather than only to react to the subsequent bill for actual use of energy one month or so after the fact.

**Demand-side Technologies**

On the customer side, the Smart Grid will make possible such things as Smart Appliances for the home or smart manufacturing equipment for industry that may turn on or turn off according to information on real-time pricing or carbon-dioxide impact, where applicable, for the power being received. Buildings or communities that store electricity (consistent with the Net-Zero concept*) may as well store and later release energy into the grid according to such information. Developments continue with Smart Appliances and some e8 members think this technology may be mature in 5 to 10 years.

* The building may be autonomous from the electrical grid and does not contribute carbon emissions

**Distributed Energy Resources (DER)**

Although regulations and requirements for DER differ from region to region, the communication capabilities of the Smart Grid will better enable the integration of these diverse power sources – some of which require further development to be practical.

* **Renewable Generation** – photovoltaic, wind, and other decentralized energy sources. PV and wind generation are available today and the technologies continue to improve in terms of energy output and cost.

* **Energy Storage** – battery, pumped water storage, compressed air, electric vehicles and others. Battery technology requires further development – perhaps 10 years – before it may be considered mature enough for economical deployment. However, these technologies will be essential to moderate the variable effects of PV and wind.

* **Fuel Cell** – PEM, Solid Oxide and others that convert fuel to electricity electrochemically with no combustion. These technologies continue to improve, yet remain too expensive for massive deployment.

* **Combined Heat and Power** – non-utility sources where industrial processes produce heat or power or both

**Grid Intelligence and Tools**

Perhaps one of the most significant outcomes of the Smart Grid for Utilities is that it will provide detailed information in real time concerning the state of the grid both overall and at specific locations. This information, in both detail and timeliness, will allow for quick action in adjusting grid conditions that might otherwise result in power interruptions.

**System Monitoring**

With large numbers of sensors deployed throughout the electrical grid, utilities will be able to ascertain exactly where problems are developing rather than waiting for a call from a customer without power. Power providers may access a wide range of system data
using different types of sensors designed to measure different parameters such as voltage, current flow, temperature, power quality and others. Thus, the Smart Grid will enable a power provider to support its particular goal(s) such as power quality monitoring or real-time monitoring for volt-VAR optimization. The Smart Grid will enable the integration of system sensors with AMI as well. While some e8 members already have transmission systems with much improved system reliability, the technology for allowing system monitoring may take another 3 to 5 years to reach maturity. Compared to the transmission system, far fewer sensors have been deployed on the distribution system. Since most Smart Grid technology will be implemented on the distribution system, the integration of data from the smart distribution system with that from customer installations – through AMI or other technologies – should result in further improvements in efficiency and reliability.

**System Operation/Management**

Real-time information about the state of the grid may allow common system operations to become automated on both the transmission and distribution systems. The Smart Grid could thus enable automatic system configuration, fault location or predictive maintenance based on wave shape analysis.

**Planning**

Historical information recorded from sensors may be used for demand forecasting and refining load curves at both high and low voltage levels. Time-sequenced information and penetration levels of various Smart Grid resources may be modeled and simulated to better understand system impacts and benefits prior to mass deployment of such resources. Through analysis of the system’s parameters and subsequent billing, energy theft could be quickly recognized and the location identified.

**Customer Offers**

With its communications technology, the Smart Grid will enable utilities to tailor rates to suit individual customers – especially residential customers – by offering incentives to purchase “smart appliances” to home management systems featuring bill management, appliance monitoring and other services. The utility may even partner with other providers of services such as cable television and security services.

Recent trials in Europe as well as parts of the United States indicate both the challenge and opportunity presented by customer offers if the customer must choose. The United Kingdom has offered an “Economy 7” TOU tariff for several years for much cheaper power used between 1 AM and 8 AM – only around 15% of households have opted for this tariff. Similar results have occurred in the state of Texas in the United States. A similar reception may be awaiting a dynamic tariff perhaps because customers have no easy method of determining their benefits vs. costs. Therefore, the power provider must meet this challenge by providing as much information to the customer as possible concerning the price of power at time of use as well as strategies for customers to use energy most economically. [22]
**Policy and Regulatory Needs**

Current policies and regulations in many regions reflect the intent to govern the mature electrical grid of the past as well as related technologies – not the developing platform that will characterize the Smart Grid for perhaps a decade or more. Moreover, such policies and regulations vary between countries, states and regions. Some countries seek to promote the Smart Grid while others have taken no action; some countries mandate carbon reduction while others mandate DER integration; others may have no real policy on carbon or DER. Conflicting government policies and regulatory bodies render attempts to implement the new Smart Grid more difficult.

In all countries, a clear policy commitment at the governmental level supporting Smart Grids would allow regulatory rules to change specifically those regarding cost reimbursement. Currently, the Smart Grid is evolving and is likely to continue to do so for some years. Today’s technology or even the next generation may be obsolete well before their investment has been recovered. Accelerated cost recovery, then, would allow utilities to make investments now and later as technology improves. Furthermore, for the Smart Grid to allow for the more efficient use of transmitted electrical power, tariffs must take into consideration the actual cost of providing that power at time of use rather than an arbitrary or average rate.

One strategy available to utilities regarding policy-makers applies to transmission and distribution (T&D): policy-makers may not be able to mandate dynamic tariffs for residential customers; however, dynamic T&D tariffs for the power suppliers may be possible. Thus, the actual cost of power production would be passed on to the customer. In this way, customer behavior may be modified and incentive for adopting dynamic tariffs in the long term may be established. [23]

**Financial Commitment**

The financial commitment necessary for implementing a Smart Grid would seem to depend on the starting point. Some e8 members already have implemented automation within their electrical systems to improve reliability while others have deployed Advanced Meter Infrastructure alone in limited quantities. Financial numbers from those e8 members who have attempted to estimate the cost of full implementation range from $1 billion USD in one geographic region to $16 billion USD for an entire country. Smart meters in one region appear to show a pay-back time of about 4 years while substation automation at the medium and low voltage level has allowed one utility to avoid penalties – even receiving a bonus from its regulators due to the improved reliability.

In a carbon market that assigns a monetary value for each ton of CO₂, the number of kWh saved may better justify the deployment of VVO devices over millions of Smart Meters as the former may be much less expensive.

**Plan/Process**

At the beginning of the process of Smart Grid implementation it may be advisable perhaps even imperative to engage with as many groups having an interest in the project as possible besides the regulating agencies controlling the area of implementation.
Members of e8 who have succeeded thus far with their current efforts partnered with consumer groups, commissions as well as vendors of the technology to be used. Past demonstrations for regulators helped educate them about the technology, its purpose and benefits. Several members have on-going or planned demonstration or pilot projects. The success of these projects will aid greatly in convincing those agencies of the merits of the Smart Grid.

Each e8 member has its own approach and focus depending on the current state of development for each with regards to the Smart Grid. For instance, e8 members in Japan already have very stable grid systems and are more directly concerned with creating a low-carbon society. One member in Northern Europe is concerned with DER integration due to their abundance of wind energy. Europe in general is driven by an initiative called “20/20/20” that members hope to achieve in part through the use of the Smart Grid. Meanwhile, in North America, relatively small pilot projects have been undertaken by e8 members in the United States and Canada regarding AMI, distribution automation and line optimization. The Italian e8 member, focusing on the issues set by the European 20-20-20 proposal, seems to be well on its way to achieving a “smarter” grid. In addition to improved reliability, installed smart meters provide two-way price and contract communication at the meter.

**Major Successes**

Improved distribution reliability through automation has already been demonstrated through astoundingly low interruption rates by those e8 members who have implemented it. System Average Interruption Frequency Index, or SAIFI, value for e8 members in Japan are below 0.2 for the last eight years while System Average Interruption Duration Index, or SAIDI, value falls under five minutes. One e8 member in Europe reports SAIDI numbers less than 20 minutes and less than 17 minutes for the last two tears respectively. By comparison, a the SAIDI value for a neighboring country was 43.69 during the same time-frame while, for some regions in the United States without similar automation and considered otherwise above average in reliability, SAIDI numbers have exceeded 60 minutes for the last eight years and have even exceeded 100 minutes for six of those years. SAIFI numbers as well have exceeded 0.70 for the last five years and exceeded 1.0 for one of those years. Clearly, effective distribution automation allows for enhanced reliability.

Where AMI/Smart Metering has been implemented, utilities such as ENEL report improvements in transparency – the customer may read his/her energy consumption, rates, and contract on the meter display. Billing is based on up-to-date meter readings. Customer inconvenience of on-site visits are eliminated by remote and fast contract changes (connections, disconnections, rates, voltage, subscription transfers etc.) performed by the contact center. Human error in manual meter reading is eliminated resulting in fewer complaints and disputes. ENEL also reports reduction of power disruptions and repair time. Other benefits from using AMI include: invoices for energy reflect real consumption; billing expenses are reduced; peak shaving and reduced load also allow for lower energy costs and reduced carbon-dioxide production; improved customer satisfaction, operational cost savings and others.
By working with regulators and other interested parties, other members such as Duke Energy have experienced success in being allowed fairly large-scale Smart Grid pilot projects.

Many other pilot projects of e8 members concerning distribution automation, different kinds of tariffs, volt/VAR control, AMI, and other aspects of the Smart Grid have just begun or have yet to be started; therefore, the benefits and lessons learned will be determined at a future date.

**Major Challenges**

The most serious impediments to implementing the Smart Grid, whether in total or in part, involve regulatory agencies and customers. Rather than assume that the public will understand and accept the Smart Grid, utilities must present an appropriate business case or cases showing its value, and communicate the value effectively to regulators and customers. This helps both groups understand what the Smart Grid is and the service improvements it may accomplish. Likewise, the utility must educate customers and consumer groups about the benefits of the Smart Grid and how to realize them. Otherwise, the lack of effective communication regarding the new technologies and the Smart Grid may result in unanticipated resistance.

A specific challenge associated with Smart Grid investment is one of timing – all the substantive costs are incurred over a relatively short deployment period (including equipment and installation costs, IT and communication requirements, data and billing systems, etc.), while the consumer and utility benefits are realized over time. Appropriate financial incentives will certainly spur additional investment in Smart Grid deployments and utilization of technology. Beyond the advanced recovery of costs, such incentives can take many forms including pre-approval of costs, advanced depreciation for replaced equipment, accelerated depreciation for Smart Grid equipment, enhanced rate-of-return, etc.

The technology currently available may not be at a sufficient level of development or cost. In the automotive industry, for instance, electric vehicles hold the promise of reducing automobile-produced CO₂ emissions dramatically; however, the state of battery technology required and cost compared to the present mature automobile technology prove to be a disincentive for many customers who would otherwise want to own an electric vehicle. In the power industry, energy storage and carbon sequestration technologies may currently pose similar problems.

Challenges posed by perception and misunderstanding may be overcome in large part through effective and continuous communication. Engaging policy makers, regulatory agencies, customers and consumer groups as well as technology suppliers throughout the process of approval and deployment will minimize the occurrence of surprise and opposition at the last moment. Effective demonstration projects will help convince regulators and customers that the benefits justify the costs. Examples follow:

**EDF (France)**
EDF is focused on full integration of all the electricity system’s elements a single, efficient, customer-oriented system that will allow the customer to manage consumption and that will enhance cost-effectiveness for utilities. Currently, a test deployment of 350,000 smart meters in Lyons and Tours will allow remote interruption, two-way communication, various price signals, and information on load curves and supply quality.

Accomplishments to date include real-time generation and transmission system and middle voltage to 20kV operation, real-time diagnosis and restoration on very high and middle voltages, real-time price signal and load shedding for industrial customers as well as real-time electronic metering with automatic switching and billing.

Current challenges include integration of intermittent renewables, real-time data management in low-voltage grids below 20kV and supply-demand balance in real time.

**AEP (US)**

AEP’s initiative in Smart Grid deployment is called gridSMART™, an integrated system involving 10,000 customers in South Bend, Indiana. This system explored direct load control (DLC) and uses GE I210 smart meters that allow time of use (TOU) pricing and serve as a customer web portal. Successes to date include very positive feedback from customers concerning the project. Web-based energy information provided consumers information on their individual usage.

Challenges involved communication between devices involving Zigbee compatibility.

**KANSAI (Japan)**

The focus of KANSAI is to achieve a low carbon society. Already having an extremely-reliable grid system, KANSAI is working to achieve an efficient, high-quality and reliable power system with efficient generation and to transmit and to use electricity by applying ICT and other new technologies such as storage batteries. Increasing photovoltaic generation and use of electric vehicles is seen as an important step in the direction of reducing CO₂ emissions. The challenge remains of effectively integrating DER into the grid.

**TEPCO (Japan)**

Working with KANSAI, and also having a system with similar reliability, TEPCO has implemented a field test program using smart meters for roughly 1000 of TEPCO and KANSAI customers. The goal is to evaluate the effects on load levelling from visualizing energy consumption, peak pricing, real-time pricing, and direct control of air conditioners. The project is currently being evaluated.

Future efforts will develop the next generation of generation distribution and demand-side technologies for balance and voltage control.
RWE (Germany)

A step-wise modernization undertaken to increase the flexibility of its grid has been the focus of RWE with consideration that both new and replacement construction be upgradable to incorporate Smart Grid technologies in the future. Therefore RWE set up several projects with the government and several partners (universities, industry, etc.) to research the functionality and integration of SmartMeter (AMI) and E-Mobility into the Smart Grid strategy. In the Project “Mühlheim zählt” –for example- 116,000 meters will be installed by the end of 2011 and backed by a comprehensive accompanying research.

RWE focuses also on investing in solutions for integrating renewable energy sources regarding storage for highly variable DER. The variability of DER remains one of the more difficult challenges of electric grids around the world but especially for places with lots of wind at one point in time and then little or no wind at another. RWE is investigating various methods and tariffs that will aid in this integration as well as “Smart Home” applications.

Hydro-Québec (Canada)

Hydro-Québec is fortunate to have a large amount of hydro-electric generation at its disposal. (36 810 MW – 98 % hydraulic). Because of Québec's specific context, which is characterized by long transmission lines, harsh weather, and customers' reliance on electricity for their heating needs, very high standards and various mitigation plans have been used in the system design to ensure the transmission system reliability.

Smart Grid projects are now focused primarily on the distribution system.

To improve the reliability of its distribution system, H-Q is implementing remote control of 3750 MV switches and breakers on 1000 feeders. So far, with roughly half of the switches and breakers remotely controlled, reliability is improving.

A Volt and VAR Control project at the distribution level is targeting to save annually 2 TWh. Hydro-Québec will install equipment at the end of 1000 feeders to monitor and control the voltage and VARs. Field measurements from pilot project have confirmed thus far the benefits of this approach.

Pilot projects currently underway seek to increase operational efficiency by eliminating manual meter reading through the use of AMI. An additional benefit will be to take advantage of AMI deployment to facilitate the gradual implementation of additional Smart Grid components and strategies.

Duke Energy (US)

Working with stakeholders and groups who have different perspectives and concerns has proven to be a major Smart Grid implementation challenge. Duke Energy worked with roughly eleven Ohio stakeholder groups that were understandably skeptical about Smart Grid. However, through effective communication with its stakeholder groups, pilot programs, and a strategic choice to develop the most adaptable platform possible with
regards to the evolution of technology, Duke Energy received approval to start its program. Duke Energy produced educational/persuasive videos and constructed an “Envision Center” exhibition space where stakeholders and political representatives could witness firsthand the benefits of Smart Grid.

Lessons learned from the effort have largely to do with communication: public perception is important and the company process should be transparent to stakeholders. Smart Grid deployment is complex. We may therefore be better served by breaking project information into smaller, more manageable “bites.”

ENEL (Italy)

The liberalization of the Italian electricity sector in the early 2000’s led to one of the most competitive markets of its kind in Europe. Nowadays Italian customers may choose among many possible suppliers. The process has triggered growing competition between energy providers and continuous performance improvements in terms of service reliability and quality to satisfy customer demand. Eleven years ago, facing this increased customer-centric commercial approach requiring differential tariffs, value added services and reduced services provisioning time, ENEL pioneered the Telegestore Project, an automatic meter management system (AMM), completed in 2006 with an investment of €2.1 billion over a five year period. The endeavor’s benefits shared by customers, power system and the utility, convinced the Italian Authority for Electric Energy and Gas to require all Italian customers to be equipped with automatic meter management by 2011.

In addition to its AMM system, ENEL has also introduced a set of innovative Smart Grid solutions, realizing the remote control of more than 100,000 MV/LV substations (i.e. 30% of the system) and the complete automation of most of them (with automatic fault clearing procedures), the Work Force Management system that represents a radical change in the crew management, the optimization of asset management policies based on a cartographic census of network assets and on a database of network events (power outage notification, fault detection etc), and the network investments optimization based on an ad hoc risk analysis.

Having already deployed Smart Metering, automation and control of MV network and Advanced Asset Management (methods and system support), ENEL is now focusing on advanced integration of Distributed Energy Resources (DER), developing a smart EV recharging infrastructure fully integrated in the grid and in the legacy ICT systems, and finalizing the “Smart Info” device, which represents the first step towards customer awareness and active demand, making available the data managed by the Smart Meters in the indoor environment, to allow the development of energy efficiency services.
4
RECOMMENDATIONS

The Role of the Utility Industry

The process of designing and implementing the Smart Grid requires leadership. The failure of the utility industry to embrace this responsibility would likely result in a missed opportunity to guide Smart Grid development – or prevent it from occurring at all. Moreover, utilities not working together to guide Smart Grid development will risk a future hodge-podge of conflicting device and software technologies between regions due to the lack of standards. If the Smart Grid holds the promise of greatly improved customer-empowerment, reliability, reduced cost and reduced pollution, some entity somewhere is likely to take control of it leaving utilities to adapt their efforts, or worse, abandon earlier efforts to align to a new direction.

Therefore, utilities – being experts in systems-oriented drivers such as reliability, power quality and system energy efficiency – must take the leading role in the development of the Smart Grid by actively engaging with and providing their broad expertise to all interested parties and stakeholders including government policy makers, regulatory agencies, standardization organizations, consumer groups, customers, equipment manufacturers and research institutes. Such engagement will require commitment both in time and resources in the coming years. Likewise, the aforementioned stakeholders should realize that utilities possess significant knowledge and experience with in the power industry and must be included in all aspects of the Smart Grid.

Research and Development/Technology Needs

One important aspect of the Smart Grid development involves standards. Prior to the broad implementation of television broadcasting, for instance, standards had been written so that broadcasting technology and receiving technology would be compatible. The technological aspects of a Smart Grid require intercommunication and compatibility. Currently, no generally-accepted standards for the Smart Grid or its components exist although several organizations such as NIST and EPRI currently are working with standards organizations such as IEC, IEEE, ANSI, ISO, CEN as well as industries involved in an effort to develop them. The IEC 61850 series, for instance, involves interconnectivity of monitoring resources that would be useful for Condition-based Maintenance – that is, replacement of equipment based on its present condition rather than a prescribed schedule or after it fails. The Smart Grid would enable the monitoring of equipment for predictive maintenance in this way.

With or without an accepted standard, products are currently being manufactured to be used with the Smart Grid. The technology and system performance of various parts of the Smart Grid must be validated with component and subsystem testing and modeling/simulation or pilot testing prior to mass deployment. Therefore, the utilities
should bring all such groups together – standards organizations and manufacturers – and provide to these groups their expertise in power systems engineering, telecommunications, energy markets and other areas.

The utilities will deploy these products and will be greatly affected by adopted standards – particularly those regarding information transfer, interoperability, cyber security and data privacy – and utilities should be engaged by these groups in order to coordinate all such efforts to assure that standards and equipment designed to those standards support Smart Grid deployment as well as operations and management.

**Policy and Regulations**

The danger inherent in legislative actions regarding the electrical grid is that the right policy does not emerge to support Smart Grid deployment. Likewise, policy decisions regarding the Smart Grid made too early may inadvertently hamper its future development – changing such policies after the fact tends to happen slowly. Legislation should accommodate innovative technologies, how grid organizations evolve, the need for greater flexibility and the need to ensure economic development, greater competitiveness, job creation and high quality security of supply [24]. Therefore, utilities must keep policy makers informed and policy makers should work with utilities to ensure that overall public policy will allow the Smart Grid vision to continue to evolve.

While policy decisions normally occur at the national level, regulatory decisions occur at the state level. In Europe, overlapping and/or complementary policy and regulatory decisions occur at both the member-State (national) and European (EU Commission and/or EU Council and Parliament) levels. Regulatory bodies from different areas may approach the Smart Grid differently. For utilities, a major regulatory issue may be the assurance of regulatory recovery of investments. Normally, utilities must prove the benefit of any project using business cases that demonstrate the benefit to customers and the Smart Grid will require the same approach – as a concept as well as for the individual systems that will comprise the physical Smart Grid.

**Customer-side Recommendations**

Some e8 members have used cash incentives to bring customers into a pilot program. Eventually, customer offers enabled by the Smart Grid for residential energy users will move away from a single rate and be based on TOU or real-time pricing. Other offers may provide incentives to purchase smart appliances and heat pumps technologies or promote Residential Energy Management Systems (REMS). Load-shedding for households will become possible to address peak demand conditions. In short, offers more similar to those for industrial and commercial customers will become possible with the Smart Grid.

Therefore, utilities should actively engage with customers to explain how TOU pricing can bring more benefit to the customer in lowering bills than the flat rates they generally expect to lower their bills.
Business Models or Opportunities

Due to various communications technologies that will be connected to the Smart Grid, new business models for utilities will become possible. One observer compares the changes to the utility industry with those to the telecommunications industry as a result of IP communications developments [25]. Some new activities may or may not be allowed by regulators in a given area. At the present time, utilities mainly act as energy providers, with a rate-recovery mechanism for infrastructure on a straight kWh rate. Future rate recovery mechanisms may come from offering energy efficiency solutions to the customer allowing the utility to become an energy service provider.

AMI will open opportunities in the area of information technology due to the sheer amount of data made possible and the need to store and analyze it. Other opportunities will arise around communications technologies due to the necessity for wireless and fiber-optic means of transmitting large amounts of data. Home area networks (HAN) and home energy management systems (HEMS) will involve devices such as smart thermostats that will communicate with the Smart Grid. Energy storage technologies will enable utilities to more efficiently connect variable sources such as wind and solar generation. All these will create new opportunities for utilities and for the customer [26].

In trying to improve efficiency and reduce CO2 and other greenhouse gas emissions, the new business model for utilities may be that of simultaneously seeking the least cost to the customer and the most profit for the utility. For instance, utilities may be able to meet renewable electricity requirements where applicable by installing their own energy storage on properties and photovoltaic equipment on roof-tops that they rent for those purposes. In this way, the utility would pay the homeowner for the stored or generated power in exchange for using the power according to the utility’s need. Emission-offset credits may also be possible. On the other hand, long-term contracts with renewable-energy providers would free the utility from financing such projects on their own. Demand response programs could be outsourced to third parties or kept within the utility [27].

As indicated earlier, federal stimulus funding in the United States had made Smart Grid development opportunities available that previously did not exist. While this funding may be considered temporary in nature, it could aid utilities in developing important parts of a Smart Grid.

The Smart Grid will make business models and opportunities for utilities possible that have never before existed. Therefore, utilities must consider what these possibilities may be, what their regional policies and regulators will allow, and then plan for the kind of energy service provider that they can become.

Stakeholders

Regulatory bodies, financial institutions, customers, suppliers and others hold a stake in the Smart Grid. These entities may appear to have compatible or conflicting roles in its functioning. In order to support the needs of all stakeholders, utilities must understand those needs and strive to educate all groups concerning the benefits of the Smart Grid and
the utility’s approach. Keeping these groups informed and engaged in the process of adopting a Smart Grid will best assure their acceptance of it. To accelerate Smart Grid deployment, we must encourage stakeholders to invest in its implementation. Revenue models and incentive schemes have to be defined and supported at political, regulatory and financial levels.

Utilities must engage their consumers such that sustainable participation becomes “second nature” and they must inform environmental groups of the positive greenhouse gas impacts of the Smart Grid.

Each stakeholder has its own primary interests and needs that utilities must consider and then determine how best to educate those stakeholder groups concerning how the utility may meet those needs.

Table 4-1. Stakeholder Groups

<table>
<thead>
<tr>
<th>Stakeholder &amp; Role</th>
<th>Primary Interest</th>
<th>Education Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumer</td>
<td>- Pay less</td>
<td>- TOU pricing suits can lower your bill</td>
</tr>
<tr>
<td></td>
<td>- Protect the environment</td>
<td>- Load shedding helps the environment</td>
</tr>
<tr>
<td></td>
<td>- TOU pricing suits can lower your bill</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Load shedding helps the environment</td>
<td></td>
</tr>
<tr>
<td>Policymakers</td>
<td>- Climate Change mitigation</td>
<td>- Smart Grids enable enhanced integration of intermittent DERs, network losses reduction, energy efficiency etc</td>
</tr>
<tr>
<td></td>
<td>- Consumer Protection</td>
<td>- Load shedding can lower utility bills</td>
</tr>
<tr>
<td></td>
<td>- Ensure a sustainable development of the Country</td>
<td>- Smart Grids enable electric mobility (Electric Vehicles)</td>
</tr>
<tr>
<td>Regulators</td>
<td>- Security of energy supply</td>
<td>- Smart Grids enable peak shaving and reduces the need for new peak load generation capacities</td>
</tr>
<tr>
<td></td>
<td>- Consumer protection</td>
<td>- Improved quality of service and demand-side management.</td>
</tr>
<tr>
<td>Financial Community</td>
<td>- Utility profitability</td>
<td>- Investment in Smart Grids makes utilities more profitable through:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Emergence of new services</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- New and smart use of electricity leading to increased sales (substitution of electricity for fossil fuels in industry and domestic customers e.g. EVs)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Better management of capacities and of distribution networks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- More efficient billing.</td>
</tr>
<tr>
<td>Environmental</td>
<td>- Climate Change mitigation</td>
<td>- Smart Grids enable enhanced integration of DERs...</td>
</tr>
<tr>
<td></td>
<td>- Management of natural resources</td>
<td>- ... and reduced investments in new generation capacities for peak load, thus reducing pressure on availability of coal, gas, etc.</td>
</tr>
</tbody>
</table>
Public-private partnerships

Partnerships between utilities and other entities are needed to deploy the Smart Grid. This includes telecommunications, IT and IP companies in the communications domain. Partnerships are also needed with developers of devices and systems such as energy storage, alternative energy generation, distributed generation technologies, charging structure for electric vehicles, and others who will emerge to develop new applications and products for the Grid [28].

One such partnership already possible where AMI deployment has occurred could involve cable entertainment services. Another could involve security monitoring services. Just as the cable industry offers bundling of services to reduce the cost of each to the customer separately, the utility industry could offer cable and security services along with electricity. Partnership between vendors may be possible as well.

Public authorities around the world may partner with utilities to provide loan guarantees and subsidies – matched by the private sector – that may enable, among other things, the design of the most optimal devices for smarter transmission networks. These incentives could also further the development of photovoltaic generation and wind deployment. The all-electric vehicle will require some connection to the utility. Companies are already designing and marketing charging stations for these vehicles. The public sector has an interest in these developments; therefore, partnerships around this endeavor will be beneficial for Smart Grid deployment as well.

All such partnerships – private-private and public-private – allow the expertise of each member to be leveraged for the benefit of all members. Table 4-2 is a partial listing of these possible partnerships.

Table 4-2

<table>
<thead>
<tr>
<th>Public-Private Partnership</th>
<th>Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Government -utility</td>
<td>Loan guarantees and/or subsidies</td>
</tr>
<tr>
<td>University-utility</td>
<td>Research and testing capabilities</td>
</tr>
<tr>
<td>Public Organization-utility</td>
<td>Broad base of knowledge along with research and testing capabilities; standards development</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Private-Private Partnership</th>
<th>Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utility-vendor</td>
<td>Collaboration on device or service deployment</td>
</tr>
<tr>
<td>Vendor-vendor</td>
<td>Collaboration on device or service development</td>
</tr>
</tbody>
</table>
Addressing developing nations

While the e8 may represent many different stages of development for the Smart Grid of the twenty-first century, each nation has as a basis the well-developed grid of the twentieth century. Developing nations may not have any such basis upon which to build. According to the World Energy Outlook for 2009 published by the International Energy Agency, around 71% of the populations of sub-Saharan Africa – close to 590 million people – have no access to electricity. Figure 4-2 illustrates the extent of world population currently and in the year 2030 without access to electricity. In its reference scenario, IEA envisions a 30% electricity demand growth in OECD countries between 2007 and 2030 (from 9245 to 11596TWh), while countries outside the OECD will see electricity consumption multiply by 2.7 within the same period (from 7183 to 17334TWh). India's consumption alone will multiply by 3.6 (from 544 to 1966TWh). [29]

![Figure 4-1: Populations without Access to Electricity](image)

A minimal or nonexistent infrastructure may or may not be a hindrance to Smart Grid efforts in those regions as, not having already spent resources to build a 20th century electric grid, developing nations may be able to jump directly to the 21st century Smart Grid. One clear indication of the urgency of working with developing nations may be seen in electrical generation and generation by fuel projections in Asia from the Energy Information Administration (EIA). Figure 4-3 indicates that not only will electrical generation increase in Eurasian regions, but that energy generated from burning coal is likely to increase dramatically as well.
Yet this outcome need not be inevitable. In addition to the massive deployment of low-carbon generation capacities (nuclear, large hydro, clean coal, wind, etc.) needed to address predicted growth in electricity demand, the Smart Grid may be the engine of change in developing countries that – while paying for itself – allows cleaner generation, efficiency, reduced costs and improves the quality of life for every citizen wherever they live. To do so, however, developing nations must have adequate access to capital, effective prioritization, plus little or no opposition to change from government institutions, regulatory bodies and the populace. As with developed nations, effective engagement and communication will be essential in order to bring the Smart Grid to developing nations. One important issue for promoting the Smart Grid in developing countries involves technology and knowledge transfer between developing and developed countries while another involves determining the appropriate technologies to apply.

The e8 is ready to support developing countries by supplying experts to accelerate capacity-building and help determine the business cases that best represent the context for the Smart Grid in each country. These business cases could then be used as the basis for choosing Smart Grid technologies for deployment.

**Becoming Smart in Stages**

The Smart Grid will be a huge undertaking and a single, best path to the Smart Grid may not exist. Prior to focusing on a specific technology, one of the first tasks may be to address how the technology or technologies best suited for deployment may be selected. Therefore, both developed and developing nations may find their own way best by focusing on business objectives specific to their country, utility, and/or customers rather than on technology alone. On their path to the Smart Grid, for instance, some developing countries may want to concentrate on implementing DER (PVs, wind, biomass, etc.) to meet energy demand and thus avoid the use of coal or hydrocarbon fuels.
More developed countries may find improving system efficiency to be a better beginning path to the Smart Grid. For example, reducing the voltage on existing systems may be a low-cost method of reducing greenhouse gas emissions. Other countries may choose to concentrate on demand response or on reliability.

To select appropriate technologies for Smart Grid deployment, one e8 member developed a three-stage approach. The first stage consists of identifying business objectives such as system performance, power flow and energy efficiency. In the second stage, applications such as remote control of equipment, volt/VAR control, fault location, and load management are identified. In the third stage, technologies are selected to provide the desired data, as illustrated in Figure 4-3. This approach serves as an example for consideration and merely represents one possible way for pre-deployment analysis.

Once the best technologies and time frame for the deployment stages have been determined, the next task is implementation.

Another e8 member has adopted a three-stage pilot plan – some of which has been accomplished – for implementing its version of the Smart Grid illustrated in Figure 4-4. This plan, while specific to one country, may offer a representative sequence of events for others, both in developed and developing nations, in implementing the Smart Grid.

The first stage for grid implementation may involve Smart Meter deployment, high and medium voltage remote operation, and medium and low voltage substation automation/remote operation. For the e8 member, the last two reduced SAIDI numbers from inception to the present by around 60%. These successes should build confidence in the overall direction of the Smart Grid among customers, policymakers and regulators.

The second stage may involve wireless IP-based communications infrastructure with MV/LV substations and remote meter management system in order to realize an integrated communication infrastructure enabling all Smart Grid applications, providing “smart info” to customers (who already have the “smart meters”) to achieve awareness,
Electric Vehicles recharging infrastructure enabling large scale electric mobility, and active control and demand response of DER for renewables integration.

The third stage (still being planned for the e8 member) may involve active demand management for low voltage customers, integration with Smart Homes (HEMs and/or HANs), and perhaps even Smart Cities as these technologies evolve.

The preceding sequence, meant purely as an example, serves to illustrate one possible approach to implementing a Smart Grid over an unspecified period of time with respect to the technology involved – it does not represent a road map to achieve a Smart Grid. Utilities in different areas may prefer entirely different approaches; however, the most important activity, using appropriate business cases to determine the best technologies and time frame, should be undertaken first.
The Smart Grid will be the culmination of approximately 120 years of development in electrical generation, transmission and distribution. Power in the old electrical grid basically flowed one way from generation though the last load. The Smart Grid will allow two-way transfer of information between power provider and customer and even power transfer to the grid from users capable of providing electrical generation. Advanced Metering Infrastructure will allow greater efficiency and accuracy in billing operations while eliminating error and significant labor costs involved with manual reading. The communications infrastructure can also enable new advanced functionalities such as, for instance, smart home appliances, electric vehicle recharging data acquisition systems, etc. Smart grid deployment will have direct impacts on greenhouse gas emissions through more efficient operation of the grid and optimal integration of distributed energy resources. Additionally, Smart Grid deployment will sensitize customers to their consumption, which has been demonstrated to result in an overall reduction in consumption.

In the event of electrical problems that would otherwise cause electrical outages for wide areas, effective distribution automation and interoperability will allow the Smart Grid to, in effect, “heal” itself. The services that the Smart Grid will enable will create business and partnership opportunities for utilities that never before existed. While the transition and investment to arrive at the Smart Grid may seem a risky undertaking, doing nothing may prove even more risky in the end as economic and political pressures combine with technological advances push society in this direction.

While the regulatory situation varies in each region, the Smart Grid, thanks to the potential of its interconnectivity, will enable business and partnership opportunities never before possible. More than electrical power providers, utilities may become energy solutions providers and more – if the right business model(s) may be identified.

The challenges utilities face with the Smart Grid involve what has been done before, what must be done now, and what must be done in the future. Regulatory mechanisms and policies in place now relate to what the grid has been up to the present time. The groundwork for the Smart Grid, regarding policy and regulation, reliability, interoperability, cost recovery mechanisms, and possible business models and opportunities must be carefully considered and put in place now so that the Smart Grid achieves its full potential.

Many drivers both for and against will influence how this new system develops; however, to do this successfully, utilities must collaborate with each other as well as all the other stakeholders having a controlling interest to guide and bring about this new creation called the Smart Grid. To overcome common barriers faced by all countries and
accelerate the development and the deployment of Smart Grid, the global partnership of e8 can play a key role.
References

[8] Wikimedia
[12] http://www.energy.gov/news2009/8216.htm (Figure by EPRI)
[14] Electric Power Research Institute
[16] TEPCO
[19] [20] Images from Electric Power Research Institute
[23] Ibid
[24] ENEL


[31] Ibid

[32] EPRI, adapted from example by Hydro-Quebec and from [33]

[33] ENEL
Acronyms

AMM  Advanced Metering Management
DSM  Demand Side Management
EV   Electric Vehicles
fy   fiscal year
HAN  Home Area Network
HEM  Home Energy Management
ICT  Information and Communications Technology
IT   Information Technology
IP   Internet Protocol
PLC  Power Line Carrier or Programmable Logic Controller
PV   Photovoltaic
REN  Renewable Energy Network
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