The Emerging Smart Grid

Investment And Entrepreneurial Potential in the Electric Power Grid of the Future

GLOBAL ENVIRONMENT FUND

CENTER FOR SMART ENERGY

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Global Environment Fund

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FOREWORD: A SMART ENERGY INVESTMENT STRATEGY

by Jeffrey Leonard, Chief Executive Officer
Global Environment Fund

In a world increasingly concerned about the price, availability and environmental consequences of conventional energy supplies, the electrical power industry stands on the cusp of a profound transition. Global Environment Fund views sectors facing disruption and technological change as providing a potentially positive investment climate for new entrants and attractive equity returns. As such, the GEF Clean Technology investment team has developed its strategy for identifying new investments that take advantage of impending turmoil and change in the electrical power industry. This strategy — somewhat contrarian — targets rapid application of existing, evolutionary technologies rather than long-term bets on revolutionary, displacement technologies.

Trends in Energy Investments

With an outlook on 2005-06, several big investment trends have emerged decisively in the energy sector:

- Investors began shifting toward real assets in the energy arena commencing around 2000. Energy generation assets of all sorts with good long-term contractual commitments have thus become more attractive for big buy-out groups and institutional investors.
- Environmental concerns, and political pressures to address those matters, have led many U.S. states, and national and provincial governments around the world, to sponsor new programs to stimulate, subsidize and incentivize renewable energy generation capacity (wind, hydro, solar, biomass).
- Both governments and private investors have sunk significant sums of research and development capital to support energy technologies thought to be at the vanguard of a new millennium in energy generation. These range from bigger megawatt wind-power turbines and new more efficient solar photovoltaic systems to large stationary fuel cells, wave energy and next generation nuclear reactors being developed for installation in the coming decades.
- Cleaner forms of existing fuels are touted as the new-old thing, as well, with clean coal and biofuels (ethanol) especially, receiving a huge political and economic push in the United States owing to the continued economic and geopolitical importance of these fuel supplies— a trend that is accentuated by the passage of the 2005 Energy Act into law on August 8, 2005.

In summary, after a long hiatus of relative disinterest, institutional investors have come to view energy generation and energy technology as highly attractive in both relative and absolute terms. Some of these trends are described in a white paper completed by Clean Edge for GEF in 2004, "A Global View of Emerging Opportunities in Renewable Energy" (available at the GEF website, http://www.globalenvironmentfund.com/Clean%20Edge%20Report.pdf).

These trends portend a mix of future power generation capacity that on the whole is cleaner than the current mix, and the advent of new technologies that are cleaner, more efficient and cheaper (with all-in costs considered) than traditional electricity generation technologies. Yet, from a venture capital investment perspective, GEF is reticent to pile on more of the conventional approach to energy and energy-related technology investments at a time of high asset valuations.

Identifying Risks in Conventional Energy Investing Strategies

While investment returns deriving from ownership of energy production assets have proven attractive of late, we see reasons to be more cautious going forward. First, a significant portion of the returns has come from the purchase of existing assets at below replacement costs and the use of highly advantageous debt financing at attractive rates. Second, substantial amounts of money have flowed into the energy asset class. We believe that the increase in the number of bidders for energy generation assets will continue to push prices up and encourage more aggressive valuations. In addition, the regulated utility sector has become a more sophisticated seller, and increasingly is using investment banking advisors to conduct high visibility auctions for assets. As for new deals, the convergence of high energy prices and political ferment means that many greenfield projects, using natural gas and increasingly renewable energy sources, are on the books for financing in coming years. Yet, we see that the internal rates of return on equity in such projects are likely to fall well below the threshold that would be expected for venture-capital investors.

In the technology area, big government, big corporations and big venture financiers appear heavily fixated in the current climate on funding new “displacement” technologies to sweep away the old order and usher in the new order of clean energy utilization. Fuel cells, hydrogen generation and infrastructure, thin-film lithium batteries, flywheel electrical storage systems, generation systems to deliver off-grid distributed and “wireless” power, and similar new technologies have drawn the bulk of the political and media attention, as well as the lion’s share of investment capital going into the energy technology sector. Some of these and many other new technologies currently on the drawing boards in labs will likely dramatically revolutionize the energy generation sector in decades to come.

Nevertheless, over the past 15 years, GEF has generally shied away from these investments. A few factors have influenced our view of the investment proposition. First, choosing the “winners” from a multitude of emergent solutions — for example, close to a dozen consortia that have licensed Oak Ridge Laboratory technology for thin-film lithium batteries — is a daunting challenge and generally an inherently risky strategy for diversified investment partnerships. Second, venture capitalist funds are not particularly well-equipped to estimate accurately the time- and cost-to-market of many “enertech” research and development programs. While strategic investors in these deals may have less sensitivity to timing and ultimate capital costs, we believe these two factors are critical to control within the context of the GEF technology investment program. This is especially true because GEF’s investment strategy generally is to deploy its capital at an early stage in the gestation of a technology cycle. In such instances, the need to wait much longer — and to raise much more capital than originally projected is all the more dilutive of our interests and debilitating of our ultimate internal rates of return.

An Investment Strategy to Exploit Energy Constraints

GEF's approach to investments in the energy technology domain has evolved since we first began investing in clean technology and clean energy companies in 1990. Since then, the GEF technology team has successfully deployed and subsequently realized capital at attractive returns in several generations of emerging companies that help traditional American industries reduce their total energy-environmental "footprint." Generally, we have focused on technologies that can be applied rapidly to aid traditional pollution and energy intensive industries to operate more efficiently and generate fewer externalities. Because three-fourths of America's electricity is generated from fossil-fuel sources, we believe that investments that enable industrial and commercial operations to cut energy consumption will have a double payoff — first, in reducing operating costs and second in reducing environmental emissions from electricity generation.

By definition, GEF's energy technology investment strategy tends to center on identifying opportunities in the "rustbelt" and the "oil patch" areas of America, where the most energy intensive, high-environmental pollution industries are located. We scour the terrain for new investments in these areas more actively than along the "hydrogen highway" of the future. And, we tend to focus much more on finding companies whose technologies are reducing energy use in industry and buildings than on those companies that are beavering away in the labs to develop the next-wave energy generation technologies.

The strategy may seem a bit of a paradox at a time when concern about supply and availability of petroleum fuels in mid-2005 has rocked international capital markets. The media and the American Congress have fixated on the needs to stimulate alternative energy sources relying on non-fossil fuel-based generation technologies. The long-term transition to more benign and ultimately (though not yet) more efficient energy generation technologies is clearly a dominant theme of the decades to come. Yet, at GEF, we believe that the memorandum received on the desk of every operating executive in corporate America in early September 2005 did not say: "Switch to renewable energy," or "Check out fuel cells." Rather the message was simple and terse: "Cut energy usage and costs — now!"

It is this urgent demand that lies at the heart of GEF's energy technology investment strategy.

Currently, our team is seeking out emerging companies offering process knowledge solutions that automate, control, and monitor manufacturing operations to enhance efficiency while reducing energy use and emissions. We believe that virtually every major manufacturing corporation in America has recently redoubled its efforts to reduce internal energy consumption — as a cost-saving measure, but also as an emissions reduction and compliance strategy as well. According to recent U.S. Department of Energy estimates, readily available technologies make realistic a goal of reducing industrial plant energy consumption by 10-15%.

In 2005, our Clean Technology investment program completed two investments that highlight and continue the legacy of our strategy to identify early mover companies deploying applied technologies to deliver energy-saving and pollution-reduction techniques to key industries:

- **Sensicast Systems, Inc.** (Sensicast) enables its industry customers, such as Nucor Corporation (NYSE: NUE), a major U.S. steel producer, to enhance efficiency while reducing energy use and emissions by using a network of wireless sensors to automate, control, and monitor manufacturing operations. Sensicast and General Electric are collaborating on a program with the U.S. Department of Energy to develop and demonstrate wireless sensor networks, with a goal of reducing industrial plant energy consumption significantly.
- **Signature Control Systems, Inc.** (SCS) is the developer of an integrated process control system to industries manufacturing non-metallic products in which chemical and phase changes occur during the manufacturing process. The industries that benefit directly from SCS' reduced energy costs and higher efficiency include those involved in molded rubber products, tires, thermoset plastics, engineered wood panels, fuel cells, high pressure laminates, bulk molding compounds and aerospace composites. These industries traditionally consume large quantities of electricity and steam for processing, and frequently create large amounts of scrap and waste material due to quality control and processing errors.

The Emergence of the Smart Grid in America

As the GEF Clean Technology Investment Team has entered into a new investment cycle with fresh equity capital, we have recently begun to take a closer look at the entire electricity distribution chain — from the point of generation to the point of use — as an investment proposition. A recent stimulus to address the opportunities to invest in technologies that can improve the operation of the electricity grid is the 1724-page, $12-billion 2005 Energy Act, which includes a call for nationwide standards for reliability and other provisions likely to stimulate new technologies and new applications that bring "intelligent" systems into the electricity management system.

In point of fact, we believe that national energy legislation in relation to the electricity grid is actually trailing, not driving, an explosion of new investment in the electrical grid in the United States. The real drivers of technological innovation in the electrical grid have been on the horizon for much of the past decade, and are now beginning to gather momentum. These include the antiquated nature of most technologies that still form the backbone of the electricity grid information system, the destabilizing and somewhat erratic effects of deregulation in the electric utility industry, demand for real time pricing and information, and the pressing need to increase efficiency.

As a result of nearly three decades of relative neglect, the entire power grid of the United States is characterized by aging infrastructure and old technology. It is estimated that at least 60% of the current equipment needs replacement during the coming decade. As the investment cycle within the electricity distribution sector reaches a critical juncture for reinvestment in and optimization of the existing infrastructure, we believe there is enormous "pent-up" demand to apply computer and electronics technologies that have already gone into the telecommunications, medical, aerospace and manufacturing industries.

Rapid adoption of such technologies will, we believe, ensue in the coming decade for several reasons. First, electricity consumers are demanding much greater efficiency and capability from their electricity grid. Electricity distribution systems must achieve far more for much less in the next round of capital expenditures through measurement, management, monitoring of entire network of power generation, distribution and utilization. Second, for first time, large investments must be made in technologies that upgrade and protect the quality of power generated as well as the reliability. This concern is driven in part by the explosion of the "digital economy," with the demand for highly reliable quality power increasingly at the core of the value proposition for computer- and Internet-based industries and the telecommunications sector. Finally, since the last time the electricity grid was modernized, the development of pervasive computing and networked devices enable pioneering companies to deploy two-way communications and networked technologies and applications throughout the electricity grid.

In short, we see that new technologies, new policies, changing pricing regimes, and de-regulation are all driving new business models in the electrical power markets. As the following report from the Center for Smart Energy states: "The electromechanical power grid of the previous century is being transformed by computers and electronics into a "Smart Grid." Utility automation and increased use of distributed generation technologies enable new uses for stand-by power, peak load shaving. We see growing technology markets in areas such as: Advanced Meters, Sensors, Monitors and Controls; New Power Electronics Systems and Networks; and Smart Equipment and Appliances.

All these areas complement and expand GEF's long-standing Clean Technology investment program focused on industrial applications and end-user energy efficiency. To assist our Clean Technology Investment Team to understand at a deeper level the technological changes taking place as the Smart Grid becomes a reality, and to help us better track emerging companies taking advantage of the new market opportunities, GEF asked the Center for Smart Energy (CSE) to prepare this white paper. We are very grateful to Jesse Berst, President of the CSE, and P.S. Reilly, Executive Vice President, for sharing their insights and expertise with GEF and our investors.

Jeffrey Leonard
Chief Executive Officer
Global Environment Fund

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Jesse Berst
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INTRODUCTION

The North American electric power system is in the early days of a profound change. The electromechanical grid of the previous century is being transformed by computers and electronics into a "Smart Grid." The same technologies that revolutionized computing, remade telecommunications and created the Internet — computers, electronics, and advanced materials — are now reshaping the electric power infrastructure.

As with those earlier digital revolutions, the application of new technologies will create both disruptions for existing participants and opportunities for startups. In the American entrepreneurial tradition, new companies and new industry leaders are likely to arise as a result of their ability to develop and deploy these new technologies.

Rising oil prices have underlined the urgent need for new approaches to electrical energy production. Governments around the world are spending to foster cleaner, renewable sources. Yet without an extended and modernized grid to carry that power where it is needed, much of the investment may not be cost effective. Meanwhile, when credit card processing centers or semiconductor factories suffer an outage, they lose millions of dollars per minute. The transition to an information-intensive, digital economy demands high-quality, high-reliability electricity, a difficult challenge for today's antiquated transmission and distribution infrastructure. For these and many other reasons, a state-of-the-art Smart Grid is fast becoming the critical backbone of both the energy and the economic futures of North America.

"Silicon will reconfigure the grid," explains Morgan Stanley utility analyst Judith Warrick. Advanced technology "will make the electric grid an efficient, smart, adaptive system — just as the Web and telecommunications systems are." Perhaps the best way to understand the Smart Grid — and the investment opportunities it embodies — is to consider how it will differ from the grid we inherited from the previous century. (See Table 1.)

North America's Enormous Electric Power Infrastructure

The North American electric power industry comprises more than 3,000 electric utilities, 2,000 independent power producers, and hundreds of related organizations. Together, they serve 120 million residential customers, 16 million commercial customers, and 700,000 industrial customers. With about $275 billion in annual sales, the industry is one of the continent's largest — 30% larger than the automobile industry and 100% larger than telecommunications. North American utilities own assets with a book value of nearly $1 trillion, roughly 70% in power plants and 30% in the grid. The continent has 700,000 miles of high-voltage transmission lines, owned by about 200 different organizations and valued at more than $160 billion. It has about 5 million miles of medium-voltage distribution lines and 22,000 substations, owned by more than 3,200 organizations and valued at $140 billion. The North American electric power industry will purchase more than $20 billion in grid infrastructure equipment in 2005, nearly one quarter of the worldwide total of $81 billion.

Table 1 — The Smart Grid of the Future	
20th Century Grid	**21st Century Smart Grid**
Electromechanical	Digital
One-way communications (if any)	Two-way communications
Built for centralized generation	Accommodates distributed generation
Radial topology	Network topology
Few sensors	Monitors and sensors throughout
"Blind"	Self-monitoring
Manual restoration	Semi-automated restoration and, eventually, self-healing
Prone to failures and blackouts	Adaptive protection and islanding
Check equipment manually	Monitor equipment remotely
Emergency decisions by committee and phone	Decision support systems, predictive reliability
Limited control over power flows	Pervasive control systems
Limited price information	Full price information
Few customer choices	Many customer choices

The U.S. National Energy Technology Laboratory describes grid modernization in terms of seven key characteristics:

1. **Self-healing.** A grid able to rapidly detect, analyze, respond and restore from perturbations.
2. **Empower and incorporate the consumer.** The ability to incorporate consumer equipment and behavior in the design and operation of the grid.
3. **Tolerant of attack.** A grid that mitigates and stands resilient to physical and cyber security attacks.
4. **Provides power quality needed by 21st century users.** A grid that provides a quality of power consistent with consumer and industry needs.
5. **Accommodates a wide variety of generation options.** A grid that accommodates a wide variety of local and regional generation technologies (including green power).
6. **Fully enables maturing electricity markets.** Allows competitive markets for those who want them.
7. **Optimizes assets.** A grid that uses IT and monitoring to continually optimize its capital assets while minimizing operations and maintenance costs.

For many reasons — a conservative industry, replacement cycles of 25-50 years, antiquated regulations — the Smart Grid will be a *revolution* by *evolution*. The transformation of the electric power infrastructure will be a twenty- to thirty-year process. Yet the Smart Grid has already begun to infiltrate the market for traditional electro¬mechanical equipment. Progress will be even more rapid within five years and positively breathtaking (by the standards of today's slow-moving utilities) by end of decade. Those who want to reap the rewards of the coming growth phase must lay the foundations today. Part of that process is to get a picture of the market, how it will develop, and how you and your company can best fit in. This white paper seeks to provide a roadmap to this new market, with a special focus on the new technologies and new business models that are likely to emerge. It is organized around the following four topics:

1. **Market Overview** defines this new area, gauges its size, and scans the market forces for and against growth
2. **Customer Overview** looks at the key customer segments and their buying behavior
3. **Vendor Overview** focuses on the changing landscape with emphasis on emerging alternatives to business as usual
4. **Opportunity Overview** explains the most likely timeline and exit scenarios

The network and the system need to be modernized and brought into the digital age. The advantages and opportunities for huge technological and economic gains are enormous.
Morgan Stanley Energy Insights, September 2005

The appendices provide greater detail in three areas:

- *Appendix A — Technology Overview* outlines the technologies that are the raw material for the modernized grid
- *Appendix B — Sector Overview* shows the Center for Smart Energy's framework for understanding how Smart Grid sectors relate to each other and to the overall electric power system
- *Appendix C — Sector Examples* describes five representatives sectors and sub-sectors

MARKET OVERVIEW

Smart Grid products — computers, electronics and advanced materials for electric power delivery — are gradually transforming the world's electric power systems. Each year they take a larger percentage of the grid infrastructure market, which stands today at $81 billion worldwide. Although barriers remain that can delay the changeover, global trends assure that this market will expand for the next decade and beyond.

Market Definition

The Smart Grid is a subset of the overall market for electric delivery infrastructure.

The electric power industry is divided broadly into three segments: *generation, delivery* and *end use*. The delivery segment is the highway system of electricity, transporting power from the point of generation to the point of use through a vast infrastructure of poles, lines, switches, equipment and software. (See Figure 1.)

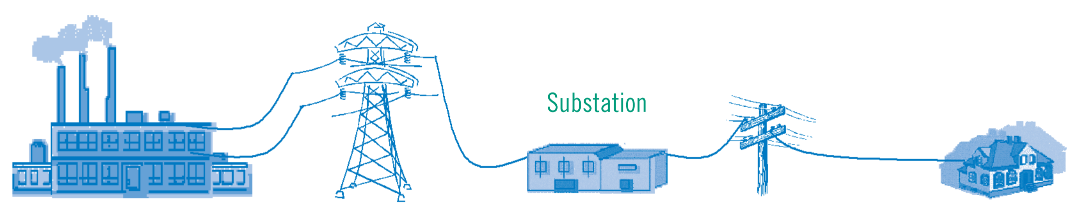

Figure 1: A simplified drawing of the electric power industry.

The Smart Grid is the application of digital technology to the delivery segment. More specifically, it is the use of computers, electronics and advanced materials to modernize and optimize the electric power infrastructure.

Transmission vs. Distribution vs. Grid

Transmission refers to the high-voltage, long-distance transfer of electricity. *Distribution* refers to medium-voltage, medium-distance transport from transmission substations to customer meters. There is tremendous overlap in the technologies and in the vendors. Among buyers, however, there is little overlap, since most utilities assign different personnel in discrete "silos." For this reason, some analysts treat transmission and distribution as separate markets. The popular press, however, uses "grid" to mean the entire infrastructure, including both transmission and distribution. We have adopted that practice in this white paper.

Both transmission and distribution use products in three broad categories, as shown in Figure 2:

- **Line infrastructure:** The poles, cables, and fittings that carry the power
- **Station (and control center) infrastructure:** Switches, breakers, transformers and other hardware along with software and services for design, construction, operation, monitoring and control of the grid. Includes substations and control centers
- **Edge infrastructure:** Hardware and software that operate at edge of the grid for such things as connecting generation sources to the grid and metering electrical usage

All three categories include both traditional electromechanical gear as well as the smart, next-generation products that are the subject of this white paper. The Smart Grid market, therefore, is a subset of the market for electric delivery infrastructure. (For more detailed descriptions, turn to the *Technology Overview* in Appendix A and the *Sector Overview* in Appendix B.)

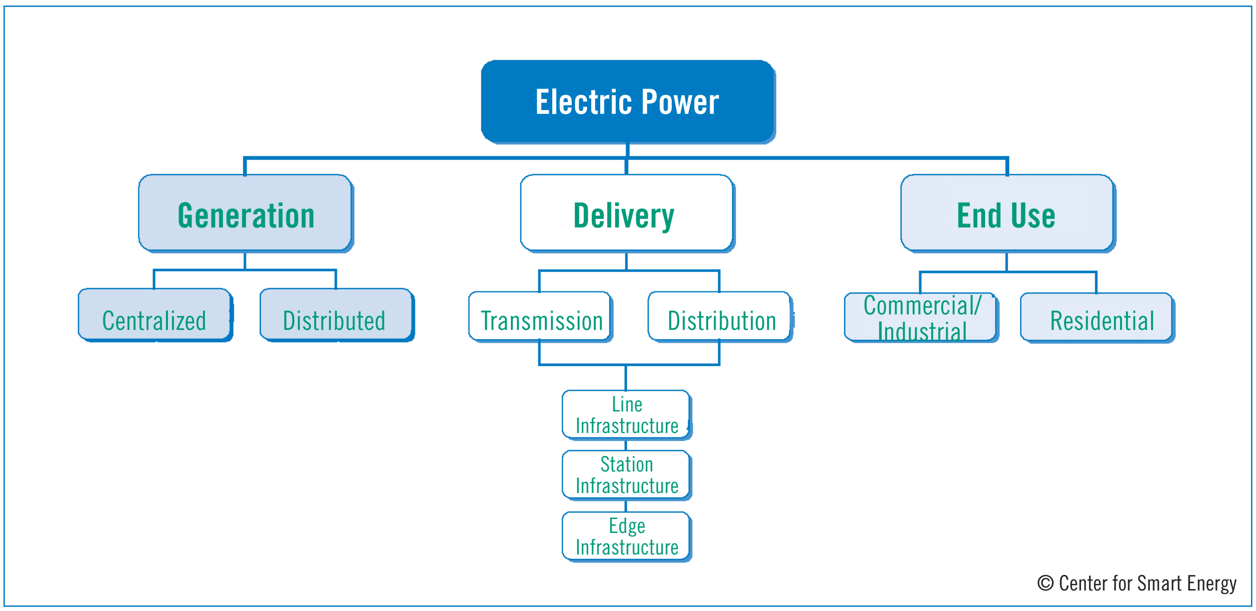

Figure 2: The Smart Grid, shown here in the center, is a subset of the electricity delivery infrastructure market.

Market Opportunity

The Smart Grid is getting a bigger slice of a growing pie. The overall grid infrastructure market stands at $81 billion worldwide. Roughly half of that is addressable by Smart Grid products, which take a larger percentage each year.

Market Size

The Center for Smart Energy (CSE) estimates the worldwide grid infrastructure market will reach $81 billion in 2005 and grow at least 5% per year over the next five years, figures generally consistent with numbers from the Electric Power Research Institute, the Edison Electric Institute, Newton-Evans and the Freedonia Group when adjusted for differences in how the market is defined. (See Table 2.)

Table 2 — Estimated Market Size, 2005 (CSE consensus estimate)

Category	Description	N. America	Worldwide Total
Line Infrastructure	Poles, cables, fittings, sensors	$9B	$37B
Station and control center Infrastructure	Substations, transformers, switches, software	$9B	$38B
Edge Infrastructure	Interconnection, metering	$2B	$6B
		$20B	**$81B**

Line equipment has less potential for replacement or enhancement by smart technologies (primarily sensors and advanced materials for cables). Taking this into account, CSE estimates that roughly $45 billion of the total is addressable by smart products. Those smart products take a larger percentage each year, although the amount differs greatly by sub-sector. For instance, in the metering sub-sector (part of edge infrastructure), about 30% of sales go to advanced meters. In the station infrastructure category, advanced digital products make up 80% of all sales in the relay sub-sector but less than 5% of all purchases in the transformer sub-sector.

Market Growth

Most projections peg the growth of the overall market (both traditional and smart technologies) at about 5% per year. That estimate, however, does not capture the growth potential of key sectors and geographies. In the U.S., for instance, energy legislation at both the federal and state levels promises to make it easier to site and finance new transmission. The Western Governor's Association is promoting a series of new transmission lines that would total more than $60 billion over ten years. Other regions, notably the Northeast, also have aggressive plans to build or upgrade both transmission and distribution (if the projects can survive not-in-my-backyard scrutiny). Meanwhile, China and India are building and upgrading power grids at record levels.

Some experts believe the numbers cited above understate the true level of the opportunity. For one thing, they include only capital spending. In reality, operations and maintenance (O&M) budgets are often used partly to buy replacement equipment or to add smart monitoring functions. For instance the Tennessee Valley Authority operates roughly 5% of the U.S. transmission system. Its capital budget typically allots $150-200 million for substations and another $80 million for O&M. None of that O&M budget would be captured in the sales estimates above, even though smart O&M is a growing market.

> The industry is planning to invest [in transmission] at levels not seen in nearly 30 years.
> **Edison Electric Institute, May 2005**

What's more, grid infrastructure does not include smart technologies on the customer side of the meter, including power electronics, building automation, wirelessly controllable lighting technologies, smart motors and many others. Although not grid technologies in the strict sense, these products are often made by the same vendors and sold through the same channels.

Market Geographies

It is important to note the differences in buying patterns and growth potential between different parts of the world.

North America
North America represents about 25% of the total market. On one hand, it has long been urbanized and its infrastructure is mature. On the other hand, portions of its grid have been pushed past capacity, leading to renewed investment. In addition, certain areas are turning to advanced technology as an answer to grid congestion, capacity and reliability. Major projects and upgrades are already underway in Ontario, California and the Northeastern U.S.

The Edison Electric Institute (EEI) periodically surveys its North American members about transmission plans. Its most recent survey, published in May 2005, documented strong growth in transmission spending. Reversing decades of decline, investor-owned utilities (IOUs) increased their annual transmission investment by 12% in 2004. And the survey revealed that growth will continue. IOUs say they will spend $28 billion in transmission infrastructure from 2004-2008, a 60% increase over the previous five years. (See Figure 3.) About half of this amount will go to line infrastructure and the other half to station infrastructure.

These figures represent only a portion of the total market:
- **Transmission only**, not distribution. Transmission is roughly 40% of the total market.
- **IOUs only**, not publicly owned utilities. IOUs serve about 75% of the population and own about 75% of the transmission assets.
- **North America only**, not the rest of the world. North America is roughly 25% of the total market.
- **Capital budget only,** not the operations and maintenance budget, which often includes money to upgrade or replace equipment.
- **Core equipment only**, not "edge" equipment such as advanced meters or customer equipment such as building automation.

When extrapolated to the total worldwide market, the EEI survey tracks closely with the market estimates cited earlier.

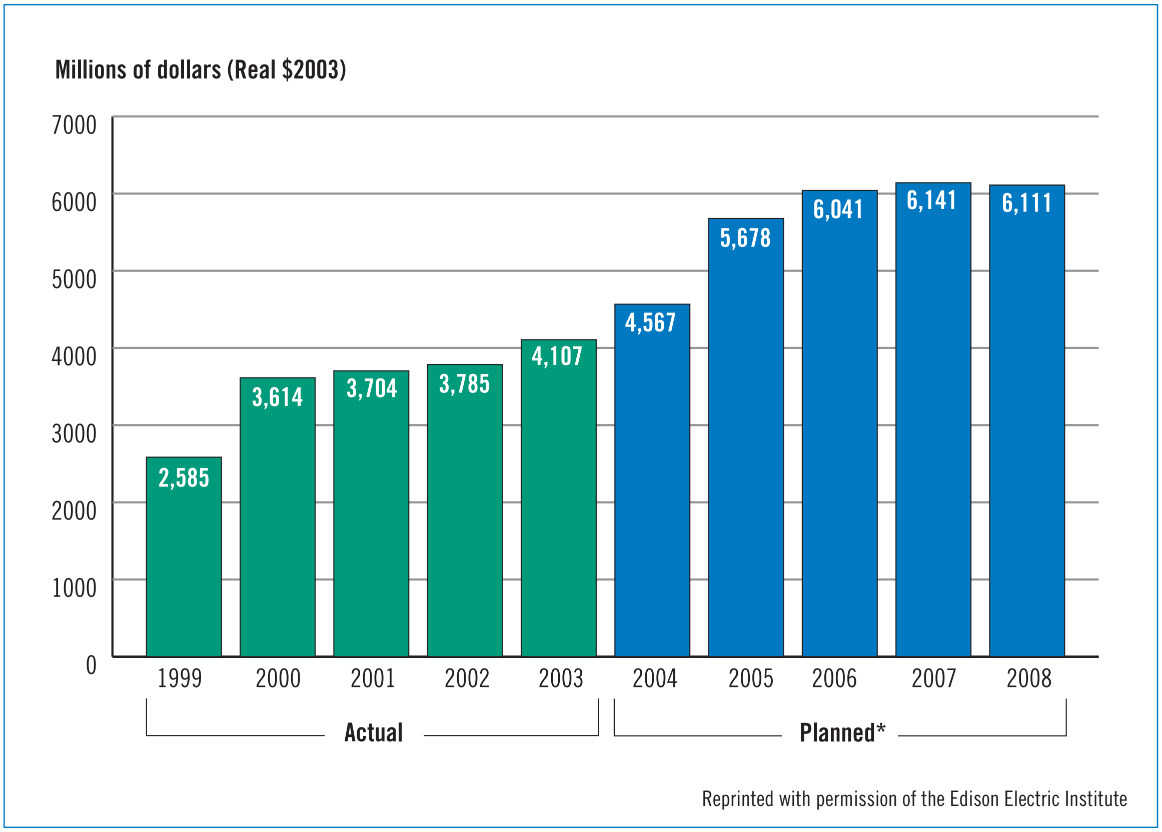

Figure 3: Actual and Planned Transmission Investment, North American IOUs.

Europe

Europe is roughly 20% of the total grid infrastructure market. Its infrastructure is mature, leading to fewer opportunities for new construction. It is already urbanized and its population growth is flat (even declining in Eastern Europe). The European market will grow more slowly than the worldwide average. Even so, it has pockets of high growth, especially in relation to wind energy, which is seeing major growth and often requires improvements to both the transmission and distribution infrastructures.

Asia/Pacific

Asia/Pacific represents roughly one third of the total market and is by far the fastest-growing geography. Home to 55% of the world's population, the region is experiencing rapid growth and urbanization. China is the growth leader as it rushes to upgrade its infrastructure. It is building power plants, regional transmission grids, and urban distribution at an unprecedented rate. Countries such as India and Thailand are also seeing above average sales growth. Only Japan, with its mature market and flat population growth, lags behind the worldwide average.

Latin America, Africa and the Middle East

Latin America is seeing rapid growth in population, urbanization, and economic activity. Those pressures toward improvements in the electric infrastructure are tempered by a fragmented market along with political and economic uncertainties. Portions of Africa and the Middle East are also seeing an upswing in new grid construction. Some countries are making wholesale renewals and upgrades. As with Latin America, the above average growth potential is tempered by political uncertainties.

Market Drivers

The Smart Grid is being pushed forward by three powerful forces — 1) a multi-billion-dollar backlog of deferred maintenance, 2) regulatory changes that necessitate technology upgrades, and 3) the substitution of "bits" for "iron."

There's little doubt that the grid will be transformed over the next 30 years, from last century's electromechanical legacy to a fully modern system for the digital world. This growth will be powered by three key *drivers* (and made easier by at least eight *enablers*, as described in the next section). The three macro forces in favor of growth are:

1. **Deferred maintenance** that can no longer be postponed, mandating billions in upgrades
2. **Regulatory changes** that cannot be met without new hardware and software
3. **The substitution of "bits" for "iron"** — using smart systems to delay or reduce the need for expensive capital assets

Deferred Maintenance

The last 30 years have seen virtually no significant investment in the North American transmission grid (and far too little on the distribution side). As one utility executive puts it: "We've been living off our trust fund... and the money has run out." North America's electric power infrastructure is aging and outmoded, as underlined by these figures from the U.S. Department of Energy:

- 70% of transmission lines are 25 years or older
- 70% of transformers are 25 years or older
- 60% of circuit breakers are more than 30 years old

Harbor Research estimates that 60% of today's infrastructure will need to be replaced in the next 15 years. The Electric Power Research Institute estimates North America must invest an additional $50-$100 billion over the next 10 years to bring the grid up to par — $5-10 billion per year over business as usual. The sorry state of the grid creates two enormous opportunities for Smart Grid vendors. The first is to replace obsolete electro-mechanical gear outright with digital technology. The second is to use advanced technology to increase the lifespan and throughput of existing gear. Today's cutting-edge products can squeeze more power through existing lines, while also making them more reliable and more secure.

Running today's digital society through yesterday's grid is like running the Internet through an old telephone switchboard.
Energy Future Coalition

Regulatory Changes

Just as the bill is coming due for deferred maintenance, the electric power industry is being hit by a flurry of regulatory changes. In most cases, utilities will not be able to comply without installing new technology. "Just the possibility of new regulations is changing the thinking of utilities," confirms market expert Chuck Newton of Newton-Evans Research. By itself, any one of these changes would be a stimulus to sales. Taken together, they will lead to years of updates and new systems. Five examples of recent changes are listed below:

Reliability and security regulations
The blackout of August 2003 and the East Coast hurricanes of 2004 and 2005 triggered new, more stringent regulations, many of which require new software, sensors and systems. The North American Electric Reliability Council (NERC), long a voluntary industry organization, is morphing into an official body with the power to impose stiff penalties. These changes will drive sales of sensors, monitoring equipment, control room equipment, software security and more. In addition, just the reporting requirements of new regulations can drive the purchase of big back end systems and large integration contracts.

Gradual restructuring
Although there have been many stumbles along the way, the developed world is gradually moving towards electric markets that allow choice and competition. The change is underway in several parts of the U.S. and Canada and is even further along in Scandinavia, the U.K. and elsewhere around the world. Competitive markets increase the shipment of power between regions, putting further strain on the aging grid and requiring updated, real-time controls. They also demand complex software for managing markets and customers.

Smart metering and time-of-use rates
The U.S. Energy Policy Act enacted in August 2005 gave states 18 months to investigate smart meters and time-of-use (TOU) rates as a way to trim the peak loads that lead to rolling brownouts and higher rates. Although it stops short of requiring states to install the systems, the legislation is certain to accelerate the move to advanced meters. It will also encourage sales of meter data management software, demand response-enabled equipment (thermostats, switches, appliances and motors that can respond to a signal), energy management software and more.

Interconnection standards
Working with standards bodies such as the IEEE, the National Renewable Technology laboratory has made great strides in creating "plug and play" standards for connecting small, distributed generation to the grid. As these and future standards are adopted around the country, they will require both utilities and equipment makers to make upgrades.

Renewable portfolio standards
A renewable portfolio standard (RPS) requires a utility to get a certain percentage of its power from renewable sources. Eighteen U.S. states and several Canadian provinces have RPS regulations or guidelines. This has utilities in the affected regions scrambling to hook renewable generation (usually wind) into their grids. Without going into technical details about intermittency and reactive power, suffice it to say that injecting large amounts of wind into the grid will require changes and upgrades.

"Bits" in Place of "Iron"

In the words of scientist Rob Pratt of Pacific Northwest National Laboratory (PNNL), "Bits are cheaper than iron." Smart technologies can reduce the need for power plants, power lines, and substations. To name just four examples:

- Demand response programs that shave peak loads, reducing the need for expensive (and polluting) peaking power plants
- Sensors and meters that show exactly where power is being used, so utilities can expand only where needed and when needed

- Electronics and control software that monitor power flows in real time, to run existing lines much closer to capacity without compromising reliability
- Sensors and software to remotely monitor expensive equipment to know when it really needs to be replaced

According to studies by PNNL, the Rand Corporation and others, the savings from measures like these could be $50-100 billion over the next 20 years.

Gradually, key stakeholders are coming to realize that "there is a whole different way to design, build and operate the grid," says Steven G. Hauser, Director of Power Grid Solutions for SAIC and a founder of the GridWise Alliance trade association. As documented in *Smart Grid Newsletter* and other publications, the next few years will see a growing number of pilots and demos that will prove a whole new approach.

"For investors and entrepreneurs, the biggest long-term potential is a radical shift away from traditional capital projects to alternatives," Hauser predicts. "These smart solutions are going to explode in the next 3-5 years." When that happens, he says, "a big percentage of grid budgets will go to replacing old equipment with next-generation stuff."

Although mainstream observers may not yet have recognized this fundamental shift, it is already underway in earnest. Bonneville Power Administration, for instance, has officially embarked on a "Non-Wires Solutions" program. It now looks first for alternatives before considering construction of new transmission. Almost always, those alternatives include advanced technology. Likewise, utilities such as ConEdison, DTE Energy, and AEP are already spending millions each year to find advanced technologies to lower the cost of needed expansion and growth.

Market Enablers

In addition to the three powerful forces for growth described above, the Smart Grid market is further aided by at least eight enablers.

Certain technical, social and political factors are not enough, by themselves, to drive transformation, but make it easier to achieve. At least eight such enablers are at work today in behalf of the Smart Grid.

Lower Cost, Higher Power Technologies

Concepts proven in telecommunications, computing, and the Internet are combining with ideas from the electric power industry itself to allow things that were impossible or too expensive ten years ago. (See Figure 4.) Although it is difficult to sum up this convergence in a few sentences, two fundamental principles stand out. The first is the replacement of the one-way, "blind" grid with two-way communications. The grid of the future will be full of sensors and switches that can monitor, report back, and accept commands. Thanks to real-time information, system operators will be able to sense, predict, diagnose and mitigate issues that might previously have caused an outage or blackout.

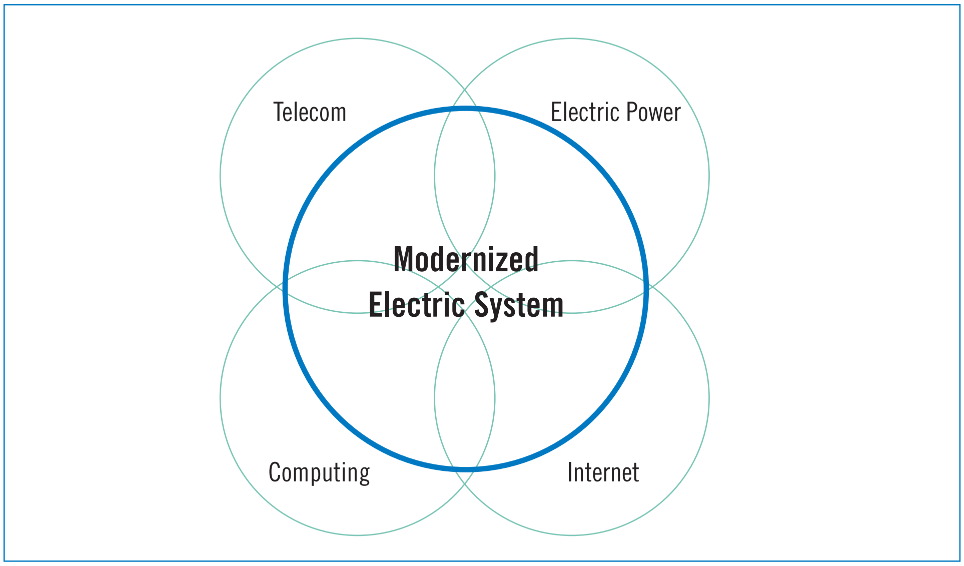

Figure 4: The Smart Grid is enabled in part by the convergence of technologies from several industries.

The second principle is the use of microprocessors and power electronics to replace electromechanical gear. This transition from analog to digital mirrors the evolution of the telecommunications industry. For instance, next-generation transformers use power electronics rather than copper windings. This leads to efficiencies — increases in voltage and current capabilities — but more importantly to new flexibility and new applications. Advanced transformers can do much more than just step power from one voltage to another. Because they are programmable, they can be used to regulate voltage output, correct for power factor, monitor power flows, and report back to the control center.

Pervasive Communications

The proliferation of cellular, paging, Internet, Wi-Fi, satellite and other nationwide communications infrastructures has given utilities a wide variety of choices for carrying messages back and forth (albeit with the burden of choosing between those many options).

The Emergence of Standards

Today, the electric infrastructure is made up of islands of proprietary technology and (literally) hundreds of conflicting protocols. As a result, utilities pay higher prices for equipment, for custom engineering and for "translation" services. At the same time, they have fewer choices than they would in a standards-based world. Standards are not a panacea, but they do give customers a greater choice of vendors and migration paths. For these and other reasons, momentum is growing for open standards. Already, Ethernet and Internet protocols are solving the lack of a universal communications language. Table 3 lists some of the other efforts now underway to build the platforms for the next-generation grid. CSE predicts these standards will come into place over the next two to three years, creating new entrepreneurial opportunities for companies that were previously locked out by the lack of a plug-and-play platform.

Table 3 — Representative Standards Initiatives		
Focus	**Name**	**Description**
Grid Architecture	DOE Office of Electric Delivery and Reliability	Supports a variety of grid R&D and standards efforts.
	GridWise Architecture Council	Formed with the support of DOE with the ambitious goal of creating the technical architecture for the next 30 years of grid progress.
	Intelligrid	Managed by EPRI, the Intelligrid Architecture is a set of communications standards and protocols. It also includes demonstration projects such as fast simulation modeling, an advanced consumer gateway/portal, and communications architecture for distributed resources.
Market Structure	North American Energy Standards Board (NAESB)	An industry forum for standards to create a seamless wholesale and retail marketplace for natural gas and electricity. Several committees are working on smart grid-related standards for the sale of electricity at both the retail and wholesale levels.
Metering	OpenAMI Task Force	A consortium dedicated to standard platforms for advanced metering and demand response.
Transformers	EPRI Advanced Distribution Automation (ADA) program	Among other things, ADA is working on a "intelligent universal transformer" that would do away with the need to custom build every transformer.
Remote Monitoring	Zigbee	ZigBee is a wireless standard that addresses the unique needs of remote monitoring, particularly on customer premises.
	I-Grid	Developed with support from the DOE, I-Grid is a system for low-cost, real-time grid monitoring and reporting over the Internet. It may eventually include a national repository of power-quality data.
Distributed Generation	NREL Interconnection Standards	The National Renewable Energy Laboratory (NREL) works closely with the IEEE and other organizations to produce uniform interconnection standards that will be "the foundation of widespread and inexpensive integration of distributed power systems."
	UL Distributed Generation Equipment and Energy Sources	This Underwriters Laboratories program includes certification of fuel cells, photovoltaics, wind turbines, and other distributed resources, as well as certification of inverters, converters and controllers.

A New Sense of Urgency

Skyrocketing prices for oil and natural gas bring a sense of urgency to all energy issues, including the grid.

A Growing Call for Action

A growing chorus of stakeholders — consumer groups, trade associations, utilities, scientists, and environmental organizations — is speaking out about the perilous condition of the electric power infrastructure and the pressing need for action. In recent years, calls for grid reform have come from scientists, national laboratories, environmental groups, consumer groups, industrial trade associations, utilities, national security experts and others.

The Electrification of Everything

Electricity, just 25% of total energy usage in the 1970s, now takes 40% and will soon hit 50% as we electrify and computerize everything from air conditioners to games to data processing centers. What's more, there is a mushrooming need for high-quality, high-reliability power for increasingly essential computers, medical equipment, and digital devices. Digital-quality power now represents 10% of total electrical load in the U.S, and is expected to reach 30% by 2020.

Increasing Emphasis on Distributed and Renewable Energy

There is a swell of interest in distributed generation (DG) — the idea of moving away from massive, expensive central plants to scattered, smaller generators close to the customer (or even owned by the customer). Likewise, interest is growing all around the world in large-scale renewables such as wind and solar farms. But you can't safely, easily and reliably hook these sources to the grid until it undergoes improvements. "Cutting-edge [grid] technologies will be required to... accommodate the additional power from massive, remote solar and wind farms," warned *Power and Energy Magazine* in early 2005.

"An explosion in entrepreneurial opportunity will occur in connecting end-use equipment and distributed generation to the grid," predicts Steven G. Hauser. "The markets for line and station infrastructure may still be largely owned by the incumbents. The most room for new players is in the gaps between end-use and the grid and between DG and the grid."

Rising Interest from Investors, Industrials and Entrepreneurs

The past few years have seen the appearance of dedicated energy technology and clean technology venture capital funds; an influx of money earmarked for energy technology from leading pension funds; public commitments to advancing energy technology from industry giants such as General Electric; and a growing number of success stories from energy technology startups. In July 2005, Dan Reicher, president of New Energy Capital, told *Business Week* that "What has changed dramatically is the number of mainstream institutions that have decided they can make money in this area."

Market Barriers

The move to a Smart Grid is inevitable in the long term. In the short term, it can be delayed by regulatory, customer, financial, and technology barriers.

There's little doubt the grid will be transformed. But there is much debate over how quickly the change will occur. Four major hurdles stand in the way:

Regulatory Barriers

The U.S. is a confusing patchwork of overlapping federal, regional, state and municipal agencies. Large projects may require approvals from dozens of different bodies, any one of which can stall the process. To make matters worse, the industry is neither fully regulated nor completely deregulated. Without clear rules, investors and entrepreneurs often hold back. In addition, current ratemaking structures make it difficult to roll out new technologies. Put in place in the middle of the last century (or even earlier), they reward investor-owned utilities for building new power plants but not for energy efficiency, demand response or grid automation. Utilities that install energy-saving systems can see their sales drop without any offsetting benefit to the utility and its shareholders.

> Uncertainty about the terms under which transmission investment may be recovered stands as a major barrier to new investment.
>
> **Consumer Energy Council of America**
> **January 2005**

Slow-moving Customers

The heavily regulated utility industry is (rightly) focused on keeping the lights on, but over the decades it has become "a culture that is, to put it politely, disinclined to use (and certainly not to seek out) new technologies," says long-time industry analyst Judith Warrick of Morgan Stanley. "The state of technological progress (or lack thereof) may shock those who have had little contact with the industry." To this risk-averse mentality is added the challenge of long sales cycles (some equipment lasts 50 years). Investors should be prepared for longer time horizons than they came to expect in areas such as the Internet, IT and telecomm.

Financial Constraints

The grid is capital intensive and faces problems imposed by utilities' constrained balance sheets, the multi-billion dollar backlog of needed upgrades and the difficulties of financing, insuring and bonding large projects. This is particularly true because the electric power industry has few large players, hence few companies able to take on big capital risks. Although its annual sales in the U.S. are 30% higher than the automobile industry, it has nothing to compare to the "Big Three" automakers in size, scale and market capitalization.

Technology Hurdles

Some Smart Grid technologies have been tested in the labs but not proven in the field or in systems configurations, something that is essential to the ultra-cautious buyers described above. The electric power industry spends far less than other industries on research, development and deployment. This issue is made worse by a shortage of architectural standards, test beds, and modeling tools and by the fact many utilities have "not-investigated-here" syndrome, refusing to accept test results unless performed on their own systems.

Many companies have overcome these challenges and gone on to great success. In fact, once a vendor is "over the wall," these same challenges are a helpful barrier to competition. Even so, investors need to be sure that their portfolio companies address not just management and technology risk, but regulatory risk. And that they have developed sales and marketing strategies to overcome the sales hurdles (including strategies to "sell the regulators" as needed).

Finally, there is an overriding macro hurdle that could delay progress — the need to "fix a moving train." Utilities cannot turn off the power for a year or two while they install upgrades. They must make the changeover without any interruptions in power. In this sense, grid modernization will resemble earlier transformations in telecomm, airlines, and retailing (the computerization that brought Wal-Mart to the fore) where existing systems had to be run in parallel as new ones were tested and rolled out.

CUSTOMER OVERVIEW

Smart Grid customers have expectations and patterns quite different from those in other high-tech markets. This section examines their segmentation, dynamics and adoption patterns.

Customer Segments

In the broadest sense, Smart Grid customers fall into two categories: 1) utilities and 2) large industrial/ commercial users. Utilities account for the vast majority of the sales, but large industrials are increasing their spending and their importance.

Table 4 list five important Smart Grid customer segments with remarks about their size and business issues. The following section explores those business dynamics in more depth.

Table 4 - Representative Customer Segments

Segment	Examples	Size and Adoption Issues
Utilities	Investor-Owned Utilities (IOUs)	• Serve roughly 75% of the customers, own roughly 75% of the assets, receive roughly 75% of the revenues, and spend roughly 75% of the money on infrastructure. • Under pressure to improve reliability and security without raising rates; increasingly looking to technology as the way to accomplish this. • Strongly siloed, with buying authority spread amongst numerous departments. • Frequent "not-invented-here" syndrome and preference for home-grown solutions. • Major purchases subject to regulatory approval and a lengthy RFP process. • Several of the largest utilities maintain their own R&D labs or contribute to joint R&D, or both. A few are now looking to turn their internal systems into products for sale to other utilities.
	Publicly Owned Utilities (POUs) — Municipals, Coops, Public Utility Districts	• Roughly 3,000 in North America. Over half have 10,000 customers or less. Munis are usually associated with mid to larger metropolitan areas. Electric cooperatives and Public Utility Districts are typically found in smaller and more rural communities. • Like investor-owned utilities, public utilities are looking to reduce costs and increase reliability although they may have more of a bias toward outsourcing. • Long a backwater, some publicly owned utilities (and their associations) are becoming pioneers as technology prices come down.

Segment	Examples	Size and Adoption Issues
Transmission Organizations	Regional Transmission Organizations (RTOs) Independent System Operators (ISOs) Independent Scheduling Administrators (ISAs) Independent Transmission Companies (ITCs) Independent Power Producers (IPPs)	• Independent transmission organizations arose as part of the move to deregulate the industry. Despite a rocky start, North America continues to move gradually toward the separation of generation from transmission. • Can span large areas and tens of millions of customers. The regional transmission organization PJM, for instance, operates the 5th largest energy market in the world, larger than all but four countries. • Transmission organizations seek to increase capacity while reducing costs. They have less of a bias toward construction — and therefore more of an open mind toward technology as an alternative — than a traditional vertically integrated utility, which seeks to recover rates based on assets. • Transmission organizations influence many buying decisions among the transmission owners, who are often the ones to actually spend the money. • This group has a strong and growing need for grid monitoring, control, visualization and planning across wide areas. • Though not technically transmission organizations, IPPs are growing and, in a few cases, buying or building grid assets.
Power Agencies	Bonneville Power Administration Tennessee Valley Authority Western Area Power Administration North American Electric Reliability Council Others	• Often market and transmit power from hydro or other sources. Other agencies are quasi-official with strong roles in setting rules and establishing standards. • Large control areas. For instance, BPA owns 75% of the transmission lines in the Pacific Northwest. • In some cases, build and own transmission. • Whether or not they own transmission, they are very influential about standards, methods, products, vendors, regulations, etc. • Both BPA and TVA have been leaders in considering, testing, and piloting Smart Grid ideas.
Large Energy Users	Industrials Commercial Chains Hospitals/HC Networks University Systems Government & Military Municipalities	• Industrial processes count for nearly 37% of total energy consumption. • More and more industries are at great risk if the power goes down. Automated manufacturing lines, financial centers, telecomm centers and data centers can lose millions per minute of outage. • Increasingly developing their own sources of power in case of outage and, in some cases, their own micro-grids.

Customer Dynamics

Smart Grid customers are far from a homogenous group. Navigating this diverse space is one of the single biggest barriers to success, even for established companies. It begins with understanding the motivations and buying behaviors of the different customer classes.

Utilities have several challenges in common. Beyond those general concerns, however, the segment includes a wide range of organizational and business models, each with its own financial, technical and regulatory issues. Large energy users also have their own special concerns. One thing they all have in common, however, is a gradual change in attitude towards the Smart Grid. Virtually every segment now contains some pioneers who are not just tolerating, but actively leading the way to a modernized grid.

Utility Similarities

Utilities of all types and sizes are under pressure to retain customers and keep rates low despite rising fuel, labor and operational costs. Many urban areas — from New York to Salt Lake City to Seattle — have growing populations that require more grid capacity. At the same time, NERC and other regulatory bodies are putting forth new security and reliability rules that require upgrades. Meanwhile, a growing number of utility customers are demanding high-reliability, high-quality, digital-grade power. All of these forces are drivers of technology adoption.

Despite the urgency of these challenges, utility sales cycles are long, complex, and confusing. Part of the problem relates to the long life of infrastructure equipment (transformers may last for 50 years). And part is due to the utility decision-making process, which often requires multiple reviews by multiple departments, followed by multiple reviews by multiple regulatory bodies. Startups with a superior solution can take years to get consideration from utilities, whose decision makers often shy away from new ideas and new companies.

Once beyond these basic similarities, however, the different utility segments have different buying needs and patterns.

Investor-Owned Utilities (IOUs)

Depending on state and provincial regulations, investor-owned utilities can be vertically integrated, owning and operating generation and transmission and distribution. IOUs are focused first and foremost on return to shareholders, but they must carefully balance cost and reliability to convince regulators they are meeting customer needs at the lowest possible cost.

IOUs buy on overall value. Cost is a factor, but buying decisions are usually driven by total cost of ownership, ROI analysis, or asset return models. IOUs' technology choices are strongly influenced by regulation — either mandates that force the utility in one direction, or policies that limit what they can recover through rates. IOUs hesitate on technology purchases if it is unclear whether regulators will allow them to recover the investment in their rates.

These large, bureaucratic organizations are comfortable doing business with other large companies. They buy more often from the big vendors, who have long-term account relationships plus the financial clout to put up the large performance bonds that are often required. Smaller companies that want to sell to IOUs must generally have a large partner or significant financial backing.

Big or small, vendors must demonstrate the ability to integrate with existing systems (which are often home grown). Rather than buying whole solutions, larger IOUs often buy equipment and do their own integration. The very largest have enough engineering staff to build their own innovations and influence the standards bodies. Indeed, some of the larger IOUs have set de facto standards in the past just by their buying decisions.

Publicly Owned Utilities (POUs)

Publicly owned utilities are owned by branches of local government or cooperatively by customers. Although typically much smaller than IOUs, they can make quicker decisions and are not always required to go through a lowest-cost-bidder process. POUs are also more likely to outsource technology and operation needs, and less likely to develop solutions in-house. With technology costs dropping, POUs can now afford systems that were previously out of their price range.

POU decisions are driven by customer concerns. If rates are high, the emphasis is on lowering cost. If reliability is poor, the emphasis is on improving service. Technology to support operational efficiency is key to either goal. As a whole, these organizations own far more distribution assets than transmission assets, although some POUs have large rural territories and therefore have medium-distance lines in their asset pool.

Municipals (one form of POU) typically base technology decisions on cost and use a request for proposal (RFP) process. They often require performance bonds, creating a significant hurdle for smaller vendors. Coops and PUDs (two other POU flavors) are more likely to use outside consultants and to buy best-of-breed products rather than go through a lengthy bidding process.

Transmission Organizations

Transmission organizations maintain operational control of the grid serving a large region of the country (even though they may not own all of, or even most of, the actual lines). Their duties include providing open access to transmission facilities; tracking power usage; settling bills; disbursing funds; and coordinating the response to outages. As compared to regulated utilities, transmission organizations are less resistant to new technology since their financial rewards are not based on regulated asset returns (which favor construction). Transmission organizations deal with different challenges depending on geography. Those in the east have many congestion issues, while those in the west must contend with long distances, stability dynamics, bottlenecks, and line sag.

Some have described transmission organizations as the “linchpin of change” because of their influence and leverage. Even when they don’t purchase the technology themselves, transmission organizations strongly influence the buying decisions of the utilities. In addition, some of the larger regional transmission operators (most notably PJM) are becoming technology leaders, acting as testbeds for new concepts and developing solutions of their own.

Public Agencies

Agencies such Bonneville Power Authority and Tennessee Valley Authority have large control centers and own significant transmission assets. In some cases, they are responsible for both transmission and distribution. They can be very influential — even dictatorial — about standards and technology choices. They are subject to broad political pressures from both the regional and federal levels. Their buying processes are similar to those of IOUs, but subject to even more public scrutiny.

Large Energy Users and Energy Service Companies

Large energy users represent a smaller market for grid products, but one that is more accessible to startups. Investors in the Smart Grid space often look favorably on companies that can sell into the industrial/commercial space while waiting out long utility sales cycles. Industrial and commercial users are primary targets for certain grid-related products, such as critical power, energy management, and sub-metering. Examples include national retail chains, major manufacturers, energy intensive businesses (such as paper mills and aluminum smelters), hospitals, high-rises, industrial parks, government buildings and military installations.

To sell to large energy users, vendors must make two cases to two groups. First, they must prove the financial case at the executive level. Second, they must demonstrate that their solution meets functional needs at the operations/engineering level. First cost and internal rates of return are the primary issues, although the total cost of ownership and the payback period influence the sale. In addition to selling directly to users, vendors can also work with Energy Service Companies (ESCOs), who typically perform energy audits and then install new technologies in return for a percentage of the energy savings.

Smart Grid Pioneers

Even four or five years ago, it was hard to find more than a handful of bellwether customers who were fully committed to grid modernization. Today, virtually every category outlined above includes pioneers who are leading the charge.

The IOU category provides numerous examples, including the five below:

- American Electric Power owns and operates its own research laboratory, which is investigating a variety of concepts including premium power parks and new methods for reactive power and voltage control. It also participates in many joint programs, including GridWise, GridApp and various EPRI initiatives.
- Consolidated Edison is working on fast simulation modeling, advanced metering, demand response and other advanced concepts.
- Southern California Edison is working on the Distribution Circuit of the Future program, with first prototypes expected in 2006.
- WE Energies is leading the Distribution 2010 program, intended in part to design and build new configurations and topologies that can support high-availability, premium-power office parks.
- Xcel Energy partnered with major vendors on the Utility of the Future program, incorporating grid monitoring, outage detection and other cutting edge applications.

On the POU side, trade associations and regional consortia have working groups actively researching advanced technologies. In part because of their shorter sales cycles, some POUs are actually ahead of their IOU counterparts in building out modernized grids. For instance, both San Antonio City Public Service and Anaheim Public Utilities are developing new, cutting edge, standards-based communications architecture that can serve as the foundations for a variety of Smart Grid applications.

As for power agencies, Bonneville Power Administration has been a world leader in understanding and articulating the Smart Grid transformation while the Tennessee Valley Authority is in the midst of a renewal campaign.

Large energy users are also becoming a voice for change. In developing countries, grid advances are often lead by large energy users, not by utilities. Industrial and commercial customers are increasingly demanding new technologies and services to stay competitive in a global economy. Companies such as Oracle, Boeing, Verizon and others have made stringent demands on the utilities serving their locations. In some cases they've gone so far as to install their own power plants, substations, SCADA systems and micro-grids.

Customer Technology Adoption Process

To understand how Smart Grid products are purchased, it is important to distinguish between new ideas and established products and to understand how a product moves from innovation to acceptance.

Utilities have a standard procedure for buying new technology. They rarely buy new things "off the shelf." Instead, they define a problem and create a Request for Proposal (RFP) that asks vendors to propose a custom solution. Eventually, as a technology becomes more accepted — as is the case already with traditional towers and poles, wires, transformers, capacitor banks, high voltage insulators, and mechanical switchgear — both utilities and industrial/commercial customers make a change. They switch to using functional requirements to buy through standard procurement processes, primarily:

- **Competitive bidding** — either direct to selected manufacturers, to qualified bidders lists, or more broadly to the entire industry
- **Sole source** to a preferred vendor
- **Basic procurement** for smaller value components

For vendors, the ultimate goal is to get the product factored into functional specifications and purchased through traditional procurement cycles, as described above. But Smart Grid innovations must first move through four phases that occur over months or even years. Table 5 below describes those phases.

As vendors create innovations, they set up engineering tests and field pilots to establish proof of concept and reliability data. Based on those early pilots, first-draft technical standards are developed, followed by wider field trials and expanded or improved standards. The resulting growth creates intense competition. Vendors battle for marquee customers. Pioneers use their early adoption of a standard for competitive advantage. Firms that were collaborative while developing a standard often end up competing for business. It can be a tough time for small firms, even if they were instrumental in establishing the standard in the first place.

Some innovations never make it past this stage. The distribution automation sub-sector, for instance, has a long list of "standards" and protocols that have never reached wide acceptance. Some standards were too closely tied to a single vendor and couldn't get industry support. Others were not advanced enough. Others were too "utility-centric," looking back to obsolete technologies and ignoring the realities of PCs and the Internet. But many standards do succeed. When that happens, they become part of the functional requirements for that type of product.

Table 5 — From Innovation to Acceptance

Phase	Outcome	Steps	Comments	Keys for Vendors
1. Innovation and Validation	Establish proof of concept and reliability measures	• Innovation developed • Engineering tests • Pilots	• Dominated by large utilities, large grid vendors, labs • Testing in cooperation with utilities or large energy users, often with funding from state (e.g. California's PIER program) or federal programs (e.g. DOE)	• Compelling technology • Testing and demonstration • Strong reputation with leading utilities
2. Standards Development	Establish industry standard	• Early deployments • Joint standards development	• Key grid standards bodies include IEEE and ASME • Technical associations that include vendors, users, and researchers try to influence standards • Regulators may also establish working groups to sort out the emerging standard • Validity data	• Links to standards bodies and regulators
3. Standards Deployment	Generate standard technical specification	• Incorporation into functional requirements • Standards education • Regulations, mandates & incentives	• Integrators and manufacturers begin incorporating the standard • Regulators are lobbied to increase adoption by removing barriers, developing mandates or adding incentives • *Note:* Many standards never make it to full deployment	• Marquee reference customers • Central role in consortia or platform efforts
4. Product Acceptance	Integrate into established buying practices	• Incorporation into new products • Broad set of utilities begin considering • Core requirements stabilized, yet differentiation remains	• Utilities begin broader integration of the standard into specifications for new purchases • Opinion-leading utilities monitored carefully as models of why and how to implement these technologies	• Brand presence • Financial strength • Product and market alliances

From Components to Solutions

Perhaps more than any other large industry, the electric power industry has been dominated by custom solutions, often developed by the utilities themselves. Gradually, utilities are becoming open to two alternatives. The first is outsourced systems integration — turning to outside companies with proven abilities to manage large projects and combine technology from different sources. The second is "total solutions" — packages of hardware, software and services that are pre-bundled to solve a business issue. Grid giants such as Siemens and ABB report that they are evolving from selling components and devices to selling systems.

VENDOR OVERVIEW

Although new entrants emerge regularly, the Smart Grid sector is still dominated by big vendors. Successful startups will be those that identify alternative points of entry and alternative sales approaches that do away with the need to go head-to-head with the giants.

Vendor Landscape

At first glance, the Smart Grid market might look like any other infrastructure sector, characterized by conventional vendors using direct sales models. In reality, there are at least four important sources of products and services.

The Smart Grid sector features products and services from the following distinct sources:

1. **"Traditional" vendors** design and manufacture hardware and software while (in most cases) also selling services and consulting
2. **Systems integrators** and consulting firms assemble and integrate solutions from a variety of vendors while often selling tools, middleware or software applications of their own
3. **Utilities and transmission organizations** are increasingly looking to commercialize hardware and software developed originally for internal use
4. **Research laboratories** sometimes provide commercial software and consulting as well as pure research

"Traditional" Vendors

The world of "traditional" grid vendors is dominated by three companies — ABB, GE and Siemens — who lead the pack in sales of both old-line equipment and Smart Grid equipment. All three are active in setting standards and moving toward a vision of grid automation and real-time operations. They are also building emerging standards (and functional requirements) right into their equipment. Table 6 provides a brief overview of these three companies.

Table 6 — Three Leading Grid Vendors

	ABB	GE	Siemens
Smart Grid Related Divisions	**ABB Power Technologies:** Power transmission, distribution and automation for electric, gas and water utilities as well as industrial and commercial customers. **ABB Automation Technologies:** Control, motion, protection, and plant integration across the full range of process and utility industries.	**GE Energy:** Equipment, service and management solutions across the power generation, oil and gas, transmission and distribution, distributed power and energy rental industries. **GE Commercial & Industrial:** major appliance, lighting and integrated industrial equipment, systems and services.	**Siemens Power:** Power generation, transmission and distribution. **Siemens Automation:** Automation and drives, industrial solutions and services, logistics and assembly systems, and Siemens building technologies.
2004 Revenues	2004 Revenues $20.7 billion All Divisions $8.7 billion Power Technologies $11 billion Automation Technologies	2004 Revenues $152 billion All Divisions $17.3 billion GE Energy $13.7 billion GE Commercial & Industrial	2004 Revenues $22.5 billion All Divisions
Headquarters	Zurich, Switzerland	GE Power in Atlanta, Georgia, US	Berlin and Munich, Germany
Comments	ABB Automation Technologies headquarters was moved to the US. ABB Power Technologies has done a good job as a thought leader despite being hampered by the financial problems of the parent.	Recent acquisitions in transformer and substation maintenance and other equipment have strengthened their grid offerings.	Siemens' strong position in edge technology areas could be better leveraged for distribution automation opportunities as end-to-end architectures emerge.

The Big Three are multi-billion, multi-national corporations with tens of thousands of employees. The Smart Grid sector has a second tier of important vendors with sales in the hundreds of millions. Typically, these companies have a leadership role in one or more sub-segments. Some examples include:

- **Line infrastructure.** Cooper Power is a major player; Schweitzer Engineering is innovating in digital relays; 3M is providing leading edge capacitors and advanced conductor materials; American Superconductor is commercializing superconductive transmission lines and grid support technologies.
- **Station and control center infrastructure.** Areva is a leader in simulations and network analysis. Several smaller companies, including Cannon Technologies (with sales growth of 40% in 2004), Electrotek Concepts, Advanced Control Systems and Optimum Technologies, have been competing with market leaders ABB and Areva to secure part of this growing market.
- **Edge infrastructure.** Itron is a clear leader in advanced metering and is assembling a soup-to-nuts lineup of related applications. Schneider Electric has been actively acquiring firms in metering, power electronics and performance contracting to strengthen its position with industrial and commercial customers.

Systems Integrators

System integrators and management consultants such as IBM Global Energy & Utilities and KEMA are also becoming Smart Grid leaders. Although they integrate and resell products from other vendors, they also develop and resell their own software, middleware, and methodologies. IBM, for instance, not only has a robust grid-related research program but also sits on several important standards bodies and participates (at its own expense) in key pilot projects. KEMA is pushing the boundaries on network security and wireless protocols. Meanwhile, software vendors such as Indus International (which sells asset management and back office suites) are presenting themselves as solutions providers and integrators rather than merely as packaged software vendors.

Utilities and Transmission Organizations

Larger utilities are in a position to develop their own custom systems and to influence standards. At different points in time, utilities have also sold those systems and competed with traditional grid vendors (typically through new companies spun out from the parent). This trend slowed at the beginning of the decade as utilities fought to get their financials under control, to recover from the Enron debacle and the California power crisis, and to cope with the economic recession of the early 2000s.

Recently we have seen early signs that this activity may resume. One example is Hypersim, Hydro-Québec's fully digital, real-time power grid simulator application, developed with Silicon Graphics and Hydro-Québec TransÉnergie. Likewise, the GridApp Consortium, formed in early 2005 with DOE support to commercialize Smart Grid ideas, includes important utilities such as ConEdison, Exelon, Southern Company, and AEP.

For Smart Grid investors and companies, forward-thinking utilities can be sources of pilots, early sales, partnerships and intellectual property.

Research Laboratories

In the Smart Grid space, research laboratories sometimes go beyond the conventional roles of creating and licensing intellectual property. They sometimes go into the market to sell their discoveries. Over the years, the Electric Power Research Institute has formed several subsidiaries to sell research and services. U.S. national laboratories have been known to sell or license grid-related services and technologies including superconductive technologies, advanced energy storage technologies, grid-friendly appliance controllers and more. In Canada, Powertech Labs, a wholly owned subsidiary of BC Hydro, sells a leading-edge software package for control centers.

Vendor Dynamics

Smart Grid startups face stiff competition from the incumbent giants. They can improve their chances by supplementing standard direct sales models with alternative points of entry and alternative sales approaches.

Even with the continued dominance of the multi-national giants, the Smart Grid sector is changing in ways that create opportunities for new entrants. Significant trends include alternative points of entry and alternative sales approaches. Solving the sales/distribution challenge is one of the toughest hurdles in the Smart Grid space. Determining whether or not a company has a cogent sales plan is one of the fastest ways to judge its long-term potential. During our interviews, many people stressed the challenge of understanding and mastering sales to utilities as the single biggest barrier to success by startups.

The first and most important path to market is direct sales. With few exceptions, Smart Grid startups must be prepared for this challenge, since they will have a hard time gaining support from distributors and independent sales reps, who focus on traditional gear and have little budget or interest for unproven innovations.

Alternative Points of Entry

In addition to building a sales force, Smart Grid companies must also look for alternative points of market entry, typically partnerships with larger firms. Those larger firms are looking for ways to differentiate; to sell a "total" solution; to get access to specialized expertise; or to get access to additional customer sets (such as rural coops or utilities in other countries). In some cases, the same company that provides a point of entry also provides an eventual exit for investors. For instance, after first working as a partner, Madrid-based IT outsourcer Telvent acquired a majority stake in GIS vendor Miner & Miner in late 2004.

Alternative points of entry for Smart Grid companies include:

- **Systems integrators** pull together larger solutions from different vendors. They are often interested in working with smaller firms to get cutting edge components to gain a competitive edge in bids.
- **Service companies** provide outsourced services to utilities. They often extend their core offerings with software and services from smaller companies.
- **Consulting engineering** is the process of designing (and in some cases procuring for and building) large projects. Leading examples include Bechtel, Black & Veatch and CH2M Hill. They will sometimes partner with smaller firms to gain a beachhead into a new sector.
- **Engineering-procure-construct (EPC) firms** are the next step beyond consulting engineering. Some utilities already outsource non-core T&D services such as engineering design, drawing, drafting, meter reading, and line repair. This practice is now expanding past individual specialized services to all-in-one engineering-procure-construct services.
- **Original equipment manufacturers** will sometimes source an innovative new technology from a small firm and build it into their larger solution. Examples are numerous, including General Electric, Areva, and Itron.
- **Hardware and software platform providers** often help to sell applications that ride on top of their systems. Hewlett-Packard, for instance, has joint selling agreements in place with Advanced Control Systems and other Smart Grid vendors, whose software provides a reason to buy more HP hardware. Likewise Environmental Systems Research Institute (ESRI) maintains a wide variety of marketing and sales programs with companies that build applications on top of its ArcGIS Geographical Information platform.

Alternative Sales Approaches

The conventional sales approach is to sell directly to customers, with an emphasis on big, investor-owned utilities. Many Smart Grid companies are turning to alternatives instead. It's not that they abandon the idea of sales to large utilities. Rather, they find alternative approaches that generate both validation and cash that can then help to unlock the IOU market. Examples include:

- **Sell to commercial/industrial companies first, then to utilities.** Prove your technology while benefiting from faster sales cycles.
- **Sell to POUs first, then IOUs.** Energy tech startups often treat investor-owned utilities as the Holy Grail. Although those giants buy in huge quantities, they do so via a cumbersome, winner-take-all RFP process that is subject to close scrutiny and performance bonding. Some Smart Grid startups are choosing to focus first on smaller, publicly owned utilities, then using that base to move to larger IOUs.

- **Sell to regulators first, then to utilities.** Some subsectors are regulation dependent. For instance, companies in the demand response (DR) space will often begin with educational programs to help regulators understand the benefits of DR technology. Only then will they market to the utilities in that region.
- **Leapfrog to friendly geographies.** Because different states and provinces have such different attitudes about Smart Grid technology, many firms leapfrog to areas with new regulation and incentives while ignoring areas that are still behind the times. This strategy requires the capital and the skill to operate multiple outposts in multiple regions.
- **Sell service instead of products.** For some segments, the focus is shifting from selling products to selling ongoing services based on those products. Comverge, for instance, sells not only demand response technologies, but also a fully outsourced "nega-watts" program. This trend is taking hold in areas of ongoing utility operations such as grid maintenance and asset management. It is also found in commercial/industrial areas such as critical energy infrastructure, chiller plant management and power reliability.
- **Sell ongoing, "evergreen" programs rather than once-a-decade overhauls.** Market research firm Frost & Sullivan reports that utilities are gradually changing their purchase patterns. Formerly, they would invest millions in a major upgrade once per decade. Now, facilitated by open, "plug-and-play" standards, they are looking at gradual upgrades every few years. As a result, vendors large and small are rethinking their marketing approach. For instance, ABB's "evergreen" model is a multi-year contract to keep critical components state of the art.
- **Leverage pilots and standards.** Large vendors (and large utilities) routinely participate in standards groups and pilot programs. Their participation lets them influence the outcome and gives them early knowledge of trends. An open standard also lets smaller firms compete on a more equal footing. For instance, the OpenAMI effort, an attempt to build standards for advanced metering, includes several smaller firms along with several industry leaders.
- **Partner with utilities.** One way to get in the door is to make the utility your partner. For instance, Broadband over Powerline (BPL) provider Current Communications is partnered with Cinergy, which provided both financial backing and allowed Current to install its technology in the Cinergy service area.
- **Sell packaged integration, rather than systems integration.** Some customers can't afford custom development. Some systems integrators are are migrating from one-off, custom application integration to "packaged integration" — pre-bundling off-the-shelf components into standard configurations.
- **Sell via consortia.** Several recent joint efforts are now contemplating ways to sell integrated solutions. Examples include the GridApp consortium developed with AEP, Exelon, Southern and ConEdison and the Distribution Vision 2010 effort led by WE Energies. Other opportunities are emerging from trade associations and economic development efforts.

In addition to having a compelling offering, companies both new and established must aggressively expand their sales approaches. New entrants will often find alternative entry points easier than traditional channels. Established vendors must pay attention to potential partners — and potential competitors — that may appear via these alternative channels.

OPPORTUNITY OVERVIEW

This section spotlights the likely evolution of the Smart Grid market and potential exit events for entrepreneurs and investors.

To this point, we have looked at the market, the customers and the vendors. With this as background, we can examine the emerging opportunities for investors and entrepreneurs. We will begin with a high-level look at the likely timeline.

Opportunity Timeline

All Smart Grid sectors will see innovation and growth throughout the next decade, but they are likely to hit tipping points in a predictable order.

Emerging technologies often languish until they hit an "inflection point" or "tipping point," when sales momentum swings decisively from the old to the new. Below is a macro-level view of the most likely Smart Grid timeline.

1. **Sensors — detecting the data.** Adding intelligence to the grid starts with sensors for virtually every piece of equipment, from cables to circuit breakers to transformers. Some of those sensors will monitor power flow and quality. Others will watch for faults and errors. Still others will watch the condition of equipment, doing away with the need for manual inspections. Forward-looking utilities are already asking vendors to include sensors in bids for transformers and other equipment, even though they don't expect to fully use the capability for several years. *Possible winners:* Sensors and the software to read the data; makers of other equipment that build sensors into their products.
2. **Communications — moving the data.** As the number of sensors grows, the need increases for a robust, open communications architecture. Current standards efforts look as if they will take root within the next 18-24 months. Leading utilities are determining their communications strategy right now. As they make choices, de facto standards will emerge, reducing risk to buyers and unleashing further growth. *Possible winners:* Communications platforms; Broadband over Powerline (as a communications backbone, not as a consumer technology).
3. **First-level integration — collecting the data.** The next challenge is to integrate the data at the substation level and from there up to the control center. *Possible winners:* Data collection and networking products and the software to talk to them all.
4. **Centralized control — using the data for visualization and control.** As control rooms gain access to more information, they need tools for visualizing what's going on, spotting problems and exceptions, remotely controlling equipment, handling outages, and forecasting. *Possible winners:* Control center software of all types, from visualization to design to fault prediction to security, especially those that can integrate data from a wide variety of sources.
5. **Security — protecting the data.** Security will be considered all along the way, but it will hit a tipping point once enough data is flowing into control centers and enough commands are flowing back out. As centralized control becomes the norm, it will be mandatory to make sure others can't "break in." *Possible winners:* Security consulting and software.

6. **Full integration — integrating the data with the rest of the business.** Real-time and historical data will be fed into asset management, workforce management, outage management and back office functions. *Possible winners:* Enterprise-class systems that can pull everything together; data warehouses and other middleware applications.
7. **Services and applications — using the data in new ways.** Although new services will appear all along, the pace will pick up once grid data is integrated into asset management and customer information systems. Demand response programs will be an early and obvious example, but expect to see innovation and fresh thinking as this stage progresses. *Possible winners:* This may prove to be the era of "designer electricity," with customers able to custom tailor an electricity package the way they can custom tailor a phone plan today.
8. **Full automation and optimization — using the data to let the grid "run itself."** The grid will never run all by itself, of course, but we know from telecommunications and the Internet that it can be much more automated than today. This will be the era of the self-monitoring, self-healing grid. *Possible winners:* Don't be surprised to see products emerging from pioneering utilities and RTOs, who will develop these complex systems for their own use and then sell them to the rest of the world.

[The Smart Grid] offers a tool for moving 'beyond the commodity paradigm... and ushering in a set of new energy services as diverse as those in telecommunications.
Electric Power Research Institute

Like any attempt to predict the future, this timeline is subject to wild cards, from regulatory changes to technical breakthroughs to recessions. What's more, it will play out at different rates in different parts of the world. Once the pioneers perfect these technologies, they can sell them for decades as the industry undergoes this historic transformation. Investors wanting to win in the Smart Grid arena should think about this opportunity timeline from the portfolio perspective, and leverage their investments across this spectrum.

Opportunity Exits

To date, the Smart Grid market has operated differently from most other high-tech sectors, but most observers believe the climate is improving for acquisitions and initial public offerings (IPOs).

Until recently, exits in the Smart Grid market have been at the extremes of company lifecycles — early or late — with less activity in between. In the past, success tended to come one of two ways: 1) an early acquisition by a major vendor or 2) a long, slow growth path. Recently, however, prospects have improved for "mid-life" acquisitions (after the company has built up greater value for its investors and founders) and potentially for IPOs.

Mergers and Acquisitions

In areas they consider core, larger grid players often make pre-emptive strikes, buying smaller companies after proof of concept. Examples include GE's 1999 acquisition of Smallworld; Itron's acquisitions in 2002 of Linesoft and in 2003 of Silicon Energy; and Areva's 2001 acquisition of Bitronics. In areas they consider peripheral, large vendors are more likely to partner with smaller, targeted companies to provide a technology. Either way, a good strategy for innovators is to partner early with a large vendor (via joint marketing or a strategic investment). They should understand that they may be negotiating with their eventual acquirer.

In addition to many examples of early sales to big companies, the Smart Grid sector also has numerous examples of slow, steady growth. For instance, digital relay kingpin Schweitzer Engineering Laboratories (aka SEL) was founded in 1982 and remains closely held, as is Alpha Technologies, a leader in critical and standby power that was founded in 1976. Power Measurement, maker of innovative metering hardware and software, grew steadily for more than 20 years before being acquired in 2005 by Schneider Electric.

Some observers think the changes in the Energy Policy Act of 2005 will empower a large-scale consolidation in the utility space, which may "trickle down" to the grid infrastructure sector. Whether or not it leads to acquisitions of grid equipment companies, it should make large grid projects easier to finance.

Public Offerings

The likelihood of successful initial public offerings (IPOs) is less clear. The sector has seen only a few examples to date. Xantrex, for instance, the BC-based power electronics company, went public on the Toronto stock exchange in March, 2004 and has continued to register strong growth in sales.

The IPO potential may improve over the next few years, thanks in part to the recent upsurge in interest by investors. One bit of evidence comes from the summer 2005 investment of more than $100 million by Internet giant Google and Goldman Sachs into Current Communications, a provider of Broadband over Powerline services. Both London's Alternative Investment Market (AIM) and American Stock Exchanges (AMX) seem to be warming up to small cap energy tech companies. The arrival of sophisticated, IPO-oriented investors may eventually create a pipeline of Smart Grid companies groomed explicitly for an early to mid-term public offering.

John McKenna of Washington, DC-based investment bank HamiltonClark writes that "the tide has turned" for energy technology, citing four reasons the investment climate for private equity is improving:

- **Energy prices** for transportation (primarily oil) are increasing and, in that climate, energy tech solutions are viewed more favorably by investors
- **More institutional and corporate investors** are looking at energy tech transactions and the size of those funds is generally larger than current energy tech investment pools
- **M&A activity is heating up** with public companies looking at private energy tech companies to round out a more diversified portfolio
- **Share prices are moving up** for micro-cap and small-cap public energy tech companies

Based on year-to-date performance ending August 30, 2005, the NASDAQ and S&P500 indices were essentially flat. By contrast, the Energy Intelligence and Optimization segment of the HamiltonClark Energy-Tech IndexTM recorded a 25% rise in the same period.

CONCLUSION

The advent of the Smart Grid is opening up large new market opportunities for emerging companies. The electric power industry is so big and so pervasive that even small sub-sectors can represent hundreds of millions of dollars in annual revenues.

To be sure, the size of the market neither pre-determines success nor makes it any easier. Success will not be easy for startups. The market is dominated by large, established players with longstanding customer relationships and strong account control. Even so, those giant firms are looking to enhance their value proposition. Many of them recognize that innovation is not their strong suit and understand the need to work with smaller firms. They can be partners or potential acquirers of savvy startups.

The Smart Grid market also contains conservative, slow-to-move utility customers. However, focusing only on the laggards gives a distorted view. In reality, pioneers are emerging across the spectrum, from rural coops to mid-size municipals, to giant utilities and transmission organizations. They are turning to advanced technology to solve their problems. Smart startups will sell to these early adopters and position themselves for rapid growth as mainstream buyers come on board.

All emerging industries go through a long startup phase, often lasting a decade or more. Although it is still in its early days, there can be little doubt that the Smart Grid's "revolution by evolution" is underway in earnest.

APPENDIX A — TECHNOLOGY OVERVIEW

The Smart Grid applies three kinds of technology to the electric power system: ***advanced hardware*** (computers and electronics), ***advanced software***, and ***advanced materials***.

For those who wish more details on the "raw material" of the Smart Grid — the component parts from which solutions are assembled — this appendix provides an overview of relevant hardware, software, and advanced materials. Those who wish additional insights into the solutions sets themselves can turn to *Appendix B — Sector Overview.*

Advanced Hardware

Whether we realize it or not, most of us are already familiar with the hardware and electronics at the heart of the Smart Grid. We encounter it every day; as the solid-state electronics that enable tiny phones and music players; as the computers we use at business and home; as the powerful networks that power the phone system and the Internet. Table 7 shows examples of the hardware that is now transforming the grid.

Table 7 — Representative Advanced Hardware

Name	Description
Advanced Meters	*Smart meters* measure power use and report via phone, Internet or wireless. They can track usage by the time of day and even turn service on or off, diagnose problems or react to price signals.
Advanced Sensors and Monitors	*Direct voltage and flow sensors* measure in real time, enabling immediate notification of problems. *Direct measurement* reports sag and temperature of cables, transformers and other devices. *Power system monitors* collect power flows, voltages and other signals for the control center. *Phasor Measurement Units (PMUs)* are used for wide-area, near real-time measurement.
Advanced Motors	*High-temperature superconducting motors* could be 50% smaller and reduce losses by 50%. *Smart motors* would allow variable speed use, power factor correction, and other capabilities.
Advanced Transformers	*Universal transformers* could provide a standardized, portable design capable of handling multiple voltages. *FACTS phase-shifting transformers* control power flow. *Next-generation transformers* utilize solid-state devices and high-temperature superconductors.
Power Electronics	*Advanced Flexible AC Transmission System (FACTS)* stabilize and control the flow of power. *Solid-State Breakers, Relays, Switchgear and Fault Current Limiters* are high-voltage, high-power digital versions of electro-mechanical gear. *Inverters and other electronics* connect distributed generation to the grid.
Computers and Networks	*Industry standard computers and networking gear* can network and control sensors, substations, and other components.
Mobile Devices	Laptops, handhelds, tablets and even smart phones give field personnel immediate access to data.
Smart Equipment and Appliances	*Smart equipment and appliances* can be remotely or automatically controlled to respond to grid conditions.

Advanced Software

Software provides the intelligence behind a smart, automated, end-to-end power delivery network. Table 8 lists representative examples of the software that can achieve this vision. These examples typically accomplish one or more of the following functions:

- Analyze large amounts of data much faster than humanly possible
- Communicate and coordinate with many nodes in a complex network
- Route commands and power flows to the proper destination
- Produce easy-to-understand simulations and visualizations
- Measure flow and usage in small increments and analyze the patterns

Table 8 - Representative Advanced Software and Systems

Name	Description
Asset Management	Inventory and track facilities and equipment. Often combined with other software such as GIS and Outage Management (see below).
Distribution Automation	Remotely monitor and control operations formerly done manually at substations and feeders.
Energy Management Systems	Pull data from tens of thousands of meters to create a single picture for analyzing loads and forecasting needs. End-user versions analyze the energy-use patterns for factories, high-rises, and office campuses.
Graphical Information Systems (GIS)	Display assets (equipment, trucks, crews) and customers on computer maps. Often used as a platform to create visual displays for other software programs.
Grid Modeling, Simulation, and Design	Tools to model complex grids, optimize design choices, and view potential consequences. Some types act as a "wind tunnel" for the grid to test options in software rather than by trial and error.
Integrated Enterprise Software	Many of today's utilities employ separate, custom-built applications for functions such as accounting, billing, and customer service. Integrated enterprise applications can reduce costs while breaking through the "silos" to give a total view of the operation.
Intelligent Network Agents	Gather data, make decisions about local switching and control functions and communicate with control centers.
Load Management	Automatically reduce the power used by customers (the load) when the grid is close to its maximum capacity. Also referred to as "demand-side management" or "demand response."
Outage and Workforce Management	Pinpoint problems, locate equipment, create work orders and dispatch crews. Often uses GIS software to create maps.
Power Systems Monitoring and Control	*Monitoring:* Up-to-the-second displays of conditions. *Control:* Automate operations to allow centralized control. *Wide-Area Management Systems (WAMS):* Perform control functions across a very large region. *Dynamic Thermal Circuit Rating:* uses sensors and software to measure the actual capacity of a line instead of an approximation.

Advanced Materials

Materials science has transformed everything from spacecraft to golf clubs. It will benefit the grid as well. For instance, advanced materials will enable cables that carry far more power at far less size and weight. They may even allow us to reach the holy grail of utility-scale electricity storage, an improvement that could dramatically reduce the cost and uncertainty of electric power. Table 9 shows several examples of advanced materials relevant to a modernized grid.

Table 9 - Representative Advanced Materials

Name	Description
Advanced cables	*Gas-insulated lines* for underground cables.
	Advanced composite conductors are lighter and carry more current than today's steel cores.
	High-temperature superconductors carry much more current than standard wires. Could also revolutionize generators, transformers and fault current limiters.
Electric Storage	*Super-Conducting Magnetic Energy Storage (SMES)* stores energy in a super-conducting coil.
	Advanced flywheels use composites or superconductors to create flywheels with greater efficiency and capacity.
	Flow batteries charge and discharge fluid between tanks.
	Liquid molten sulfur batteries built to utility scale.

APPENDIX B — SECTOR OVERVIEW

The Center for Smart Energy has developed a schema to illustrate how Smart Grid sectors relate to each other and to the electric power industry as a whole.

As noted at the beginning of this white paper, market researchers often segment the grid into line infrastructure, station infrastructure and edge infrastructure. Although useful for a summary picture, that simplistic schema does not capture how customers buy and use Smart Grid products and services. The Center for Smart Energy (CSE) has developed a framework that illustrates the most important grid sectors affected by the smart revolution along with their relationship to each other and to the overall electric power industry. (See Figure 5.)

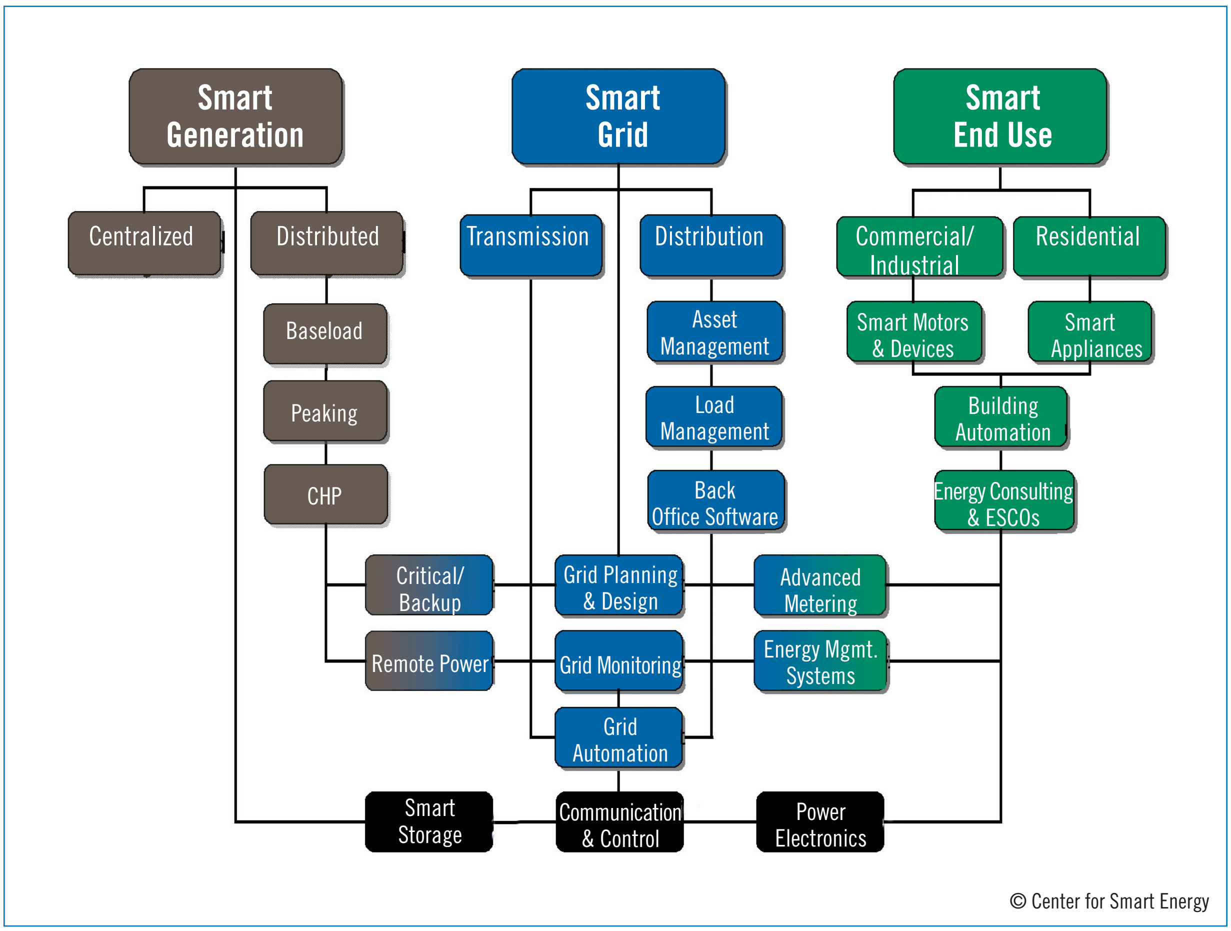

Figure 5 – Key Smart Grid sectors (shown in the center) and their relationship to generation and end use.

Smart Grid sectors are shown in the center of the diagram. Some sectors relate primarily to a single area. For instance, *load management* relates primarily to the distribution portion of the grid. Other sectors relate not just to the grid, but also to generation or end use. *Advanced metering*, for instance, takes place where the grid intersects with end use, and the drawing uses dual shading to illustrate this dual relationship. Still others (shown at the bottom) are relevant to all three parts of the energy value chain: generation, delivery and end use.

Each sector in this drawing can be further subdivided into two to ten sub-sectors. Although this white paper does not have the space to deal with the dozens of sub-sectors, it offers this schema and the brief descriptions below as a framework for understanding the Smart Grid space and the opportunities it offers to investors and entrepreneurs.

Advanced Metering. Digital power meters provide the ability to remotely monitor and monitor power usage and (increasingly) the ability to perform other functions such as monitoring power quality, voltage, theft detection, remote connect/disconnect, prepaid electricity purchases and more. The category includes communications systems for transmitting data and software for collecting and analyzing that data. That software may also interface with grid planning and design, with back office software such as customer information systems and with energy management systems.

Asset Management. Systems for managing the key assets of a utility, most notably field assets (equipment) and the workforce. Although vendors are beginning to aim for total solutions, most offerings in this sector focus on one particular problem, such as mobile workforce management, or outage management. The sector includes both software (for instance, GIS-based systems for mapping field assets) and hardware (e.g., wireless devices for trucks or handheld computers for workers). It is increasingly important for asset management solutions to accept real-time information from meters and from SCADA systems, to map assets using GIS software, and to integrate smoothly with back office software.

Back Office Software. Systems for billing, accounting, financial planning and other back office functions. Increasingly, solutions in this category are designed to accept data from other applications such as advanced metering and asset management.

Communication and Control. Platforms and standards for two-way, interactive communications. Sensors will transmit information to control centers. Control centers will transmit commands back out. This sector is in flux as it gradually moves away from proprietary, one-off designs towards common standards and object models. It is also in turmoil as customers try to choose from a variety of options, including BPL, cellular, Internet and various flavors of wireless. This sector interacts and overlaps with the grid monitoring and grid automation sectors.

Critical/Backup Power. The hardware and software to supply high-quality power when the grid fails.

Energy Management Systems. An EMS gathers information about energy usage to create a single picture and a single control point. Utilities use them to manage thousands of customers. End users employ them to manage high-rises, campuses and factories.

Grid Automation. Although transmission automation and distribution automation are typically purchased by separate departments within a utility, they both use the same basic technologies to replace old-style electromechanical products with new digital technologies for remote switching, protection and control. This sub-sector encompasses "first-generation" automation systems such as FACTS and SCADA as well as newer alternatives. On the transmission side, next-generation control center tools are an emerging area. Grid automation is closely coupled with the grid monitoring sector.

Grid Monitoring. Encompasses a variety of hardware and software for remotely monitoring transformers, feeders, switches, capacitor banks and other grid-tied assets. Hardware examples include wireline sensors, equipment sensors and condition monitors, voltage sag correctors and many others. Software examples include security software (both cyber security and monitoring for physical security) and software for collecting the data and analyzing it for load modeling, problem detection and prediction.

Grid Planning and Design. Computer tools to model, simulate, design, optimize and construct grid facilities. Increasingly draws on near-real-time information from the grid monitoring sector.

Load Management. Products in this category allow a utility to respond to a spike in demand. For instance, several firms make products that can aggregate backup generators and turn them on remotely if needed to prop up the grid during peak usage. Demand response products take the opposite approach. Rather than temporarily increasing supply, they temporarily reduce demand, often by remotely turning off (or turning down) customer equipment.

Power Electronics. Power electronics can come into play for generation, for delivery or for end use. At the point of generation, they invert, convert, and condition electricity from sources such as diesel generators, wind turbines, solar panels and fuel cells. At the point of delivery, electronics are needed to control, condition, connect, and step power up or down. At the point of consumption, power electronics find many uses including advanced power supplies, power quality, power factor correction and more. A growing sub-sector is distributed generation (DG) interconnection, where standards are beginning to emerge.

Remote Power. Remote power comes into play where grid power is unavailable. More and more remote power solutions include their own micro-grid components for distributing electricity to a village, outpost or military encampment.

Smart Storage. Using advanced materials and electronics to create utility-scale electric storage. Although it is still not economical to store huge amounts of electricity until needed, it is feasible to store enough to, for instance, provide reactive power, voltage support, or peak support. Technologies in use include large liquid (flow) batteries, high-cycle solid batteries, flywheels, pumped storage and Superconducting Magnetic Energy Storage (SMES).

APPENDIX C — SECTOR EXAMPLES

This section presents examples of five emerging Smart Grid areas.

The Smart Grid space consists of dozens of sectors and sub-sectors. This section presents quick overviews of five areas, selected because they represent the types of opportunities now materializing:

- Advanced metering
- Broadband over Powerline
- Critical power
- Distribution automation
- Networked energy platforms

Advanced Metering

With 300 million electric, gas and water meters in North America and another billion in the rest of the world, the replacement of old electro-mechanical meters with new advanced units represents an enormous opportunity — even before considering brand new sales in growing countries such as China and India. The U.S. Energy Policy Act of 2005 contains provisions that direct all states to consider advanced metering — a mandate that is sure to create a flurry of activity.

The sector comprises four main areas:

1. **AMR** (**automated meter reading**), an add-on unit that transmits data from an existing meter
2. **Advanced meters**, which typically have embedded AMR communications along with additional functions such as time-of-use metering
3. **Communications platforms**, that carry the signal from the meter to the control center (and can be used to carry other data as well)
4. **Metering data management software**, which collects and analyzes the information from the meters

> We have seen a tremendous amount of activity in metering and other areas of distribution such as GIS, asset management, workforce management, and outage management.
>
> **Utilipoint, May 2005**

In 2004, sales for all types of meters were $5 billion worldwide and $1.8 billion in North America. Overall sales grew only 3%, but advanced meters jumped nearly 20% and now comprise just under one-third of all sales. The category is undergoing a period of tremendous transition, constant innovation, and enormous price pressure. Market drivers include the arrival of off-shore manufacturers, who are beginning to "commoditize" the basic functions and drive down prices. Other growth factors include regulatory mandates in the new U.S. energy bill and in important areas such as California and Ontario. The emergence of standards, still in the flux but likely to solidify over the next 24 months, will also accelerate adoption and may be a catalyst for industry consolidation.

Despite the large market opportunity, the existence of entrenched, well-financed suppliers make this sub-sector challenging for a startup that wants to provide a full line of products. Better opportunities may lie in communications platforms or in specialized applications such as prepaid metering. Market leaders include Cellnet Technology, DCSI, Elster Electricity, Hunt Technologies, and Itron, Noteworthy private and venture-backed players include Carina Technology, Eka Systems, Silver Stream Networks, SmartSynch, and Tantalus Systems.

Broadband Over Powerline

Broadband over Powerline (BPL) is a subset of a larger sector known as Communication and Control. BPL transmits voice and data over existing electric power lines. In theory, BPL can be a dual-use technology. First, utilities can use it to transmit information from meters, sensors and substations back to the control room. Second, they can sell broadband access to consumers. BPL proponents claim theoretical speeds from 10-100 Mbps to each home, better than most of today's DSL and cable connections.

BPL is in the news these days, making it difficult to separate the reality from the hype. In 2004, both FERC and the FCC blessed the BPL concept. High-profile Internet companies such as Google and Cisco have invested in BPL startups, as have well-known venture capital firms. The U.S. has two dozen field trials and three rollouts underway and Europe is seeing even more activity. The market currently stands at only $30 million in annual sales, but the Shpigler Group forecasts the sector will hit $2.9 billion by 2009, while Telecom Trends International puts it at $4.4 billion by 2011.

It is difficult to see how BPL can achieve those aggressive predictions. BPL faces steep hurdles. A lack of plug-and-play standards forces utilities to buy everything from a single vendor, keeping prices high and raising the specter of vendor lock-in. Both the cable and DSL industries are years ahead in selling consumer access and can be expected to lower prices as needed to maintain share. In addition, cable providers (and to a lesser extent DSL providers) will benefit from lock-in as customers grow accustomed to value-added services such as phone services, digital video recorders, and on-demand content. Clearly, utilities will have to partner with, or lease their bandwidth to, established players to compete.

The situation may be better in Europe, where most governments see BPL as an important infrastructure with reliability and societal benefits. As a result, they are encouraging and incentivizing BPL. It is no surprise that Europe already leads the U.S. in actual rollouts (as compared to toe-in-the-water tests).

But the biggest long-term challenge is the emergence of new technologies such as WiMax and fiber (both of which are now rolling out in several U.S. cities). Both promise equal or higher bandwidths at lower cost than BPL technology.

The BPL sector is dominated by startups, several of which have significant investments from leading utilities, leading tech companies, or both. Notable examples include Ambient, Amperion, Communications Technologies, Current Communications, Gridstream Technologies, Ibec, Main.net, and PowerWAN.

To see big growth in North America, BPL will need to justify itself as a communications backbone for utilities or as a last-resort access method for rural regions where governments are willing to subsidize the cost. We predict the category will grow rapidly for the next two years on the basis of trials and limited rollouts but that growth will slow markedly thereafter, leading to failures and consolidation. Successful companies will be those that turn BPL into part of a larger portfolio of services.

Critical Power

Critical Power is an emerging sector with excellent prospects. Over $250 billion has been invested over the last decade to ensure the uninterrupted supply of high-quality power to critical facilities and equipment. The sector addresses three customer concerns:

- **Power quality** — spikes and dips in voltage
- **Power reliability** — short-term outages from a few minutes to an hour
- **Power resiliency** — mid-to-long-term outages from hours to days from natural disaster or even terrorist attack

Typical solutions often combine three things:

1. *Power quality components* — uninterruptible power supplies, transient voltage surge protectors, filters, voltage regulators, and power analyzers
2. *On-site generation* — powered primarily by diesel, but sometimes by renewables or fuel cells
3. *Storage* — batteries, flywheels, and thermal storage

Engineering and ongoing management services round out the category.

The market for small to mid-sized on-site generation (25 MW or less) is growing rapidly. Researchers expect users to buy 30 gigawatts (GW) of on-site generation over the next five years, compared to 2004 sales of well under 1GW. The Combined Heat and Power sub-sector (units that provide both electricity and usable heat) is predicted to reach $10 billion in annual sales in 10 years.

On the utility side, sales are driven by the need to reduce peak loads and grid congestion. On the industrial side, drivers include concerns about grid vulnerabilities, fluctuating power markets, and damage to sensitive equipment. Major customers include utilities, telecommunications facilities, financial institutions, hospitals, airports, data centers, emergency response centers, manufacturing plants and critical government agencies. On both sides, customers are demanding packaged, integrated solutions tailored to their specific requirements.

Some of the sub-sectors (such as uninterruptible power supplies) are too commoditized and too dominated by large players (such as Liebert) to have much opportunity for small entrants. Other sub-sectors, such as power electronics and voltage regulation, still have room for emerging companies. As products continue to commoditize, there will be more M&A and alliance activity, with vendors collaborating to present integrated solutions. Integrators focused on a particular industry will have an opportunity to grow and become attractive acquisition candidates for larger companies that make the component parts.

Distribution Automation

Distribution automation, a subset of the larger grid automation sector, refers to equipment and software inside substations and control centers. Market researchers peg it at $300 million to $600 million in annual sales. They expect growth of 5-10% in the next two years, with the potential for double digit gains further out. Market drivers include 1) *asset management* — getting more life out of aging assets through automated solutions; 2) *real-time operations* — understanding and operating as things occur rather than using estimates or excessive safety margins; and 3) *distributed generation* — accommodating small generation sources scattered throughout the system.

ABB and Areva are the leaders among major vendors. Coopers and Advanced Control Systems are seeing rapid growth. Some of the most interesting opportunities may lie with systems integrators and consulting engineering firms. Some of those organizations are buying stranded product sets to create their own brands and/or developing their own software. They have the advantage of a strong channel to customers, plus real-world knowledge of what those customers want. Examples include Chicago-based Sargent & Lundy and Idaho-based Power Engineers.

Networked Energy Platforms

Networked energy platforms monitor and control remote energy assets, whether sources of power, sources of load, or both. They are an increasingly important sub-sector of the area known as Energy Management Systems and often interact or overlap with products in the load management sector. Some solutions only monitor power use while others also control it either manually or automatically. Still others allow the user to optimize energy use. Some offerings handle a building or campus; others can manage assets across a wide geographical area.

This sub-sector is an example of the way the convergence of technologies can make new markets possible. Until recently, traditional control equipment has been too expensive, too difficult to retrofit, and too costly to maintain for this category to grow significantly. With the emergence of widespread, low-cost control technologies (including retrofit devices), costs are now dropping and businesses can more easily justify the monitoring of people and assets.

On the utility side, the growing interest in demand response (curtailing customer loads during peak periods) is driving interest in networked energy platforms. In that space, some firms have developed business models not around equipment sales but around using their own platform. Some aggregate demand reductions and sell those “nega-watts.” Others aggregate distributed generation, make it remotely dispatchable and sell it to utilities for use during peak periods. On the industrial side, asset management and security are joining cost management as primary motivators for deploying networked energy platforms.

The category is still emerging and highly fractured, and marked by battles over standards and communication protocols. Vendors gaining market traction include Echelon, EnergySolve (recently merged with Nxegen), EnerNOC, Celerity, Comverge, and others. Scaling up sales and marketing will be a challenge. Those that partner with tier one system integrators will be more successful than firms relying on superior technology as their primary competitive weapon.

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