Global Environment Fund

Global Environment Fund (GEF) is an international investment firm that invests in clean technology and emerging markets. The firm manages private equity funds totaling approximately $500 million.

GEF was established in 1990 to invest in, and provide management support to, companies that make positive contributions to environmental quality, human health and the sustainable management of natural resources. The Firm's investments focus especially on companies whose business operations deliver measurable environmental improvements through deployment of improved environmental infrastructure and "clean" technologies. GEF's investment objective is to provide superior returns by harnessing the power of technological innovation to promote energy sources and means of production that are cleaner, cheaper, more efficient, and more sustainable.

GEF Management Corporation, the General Partner of GEF's investment funds, is an SEC-registered investment management fi rm. GEF's Team is an energetic group of internationally experienced investment professionals with complementary backgrounds and specialized skills in private equity, project finance, legal structuring, corporate governance and business enterprise development.

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GlobalSmartEnergy

GlobalSmartEnergy is a research consultancy that helps investors, corporations and regions find their best opportunities in the emerging smart energy sector. It maps markets to assess investment potential, recommends market entry and M&A strategies, and researches economic development potential.

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Table of Contents

Foreword

BY JEFFREY LEONARD
Chief Executive Officer, Global Environment Fund

Facing record high petroleum prices, Americans are scared and confused about what our country can do to secure affordable, reliable energy supplies for the future. Higher oil prices have slowed economic growth, and forced consumers and industries to cut back or face hardships. A simplistic world of open commerce (with a return to gunboat diplomacy if necessary) and redoubled domestic exploration is tempting to imagine as a tonic for high prices. But, lower prices alone are no longer the answer for America. The era of cheap, abundant petroleum—the cornerstone of the 20th century American way of life—is over, even if in coming months or years oil prices fall back to more reasonable levels. After 60 years of economic policies and international diplomacy favoring free trade in and high consumption of oil, the country must now reckon with the fact that our high dependence on oil for transportation, in particular, poses serious national security threats, exacerbates the trade imbalance, and has massive negative environmental consequences at the local and global levels. Weaning America of its addiction to oil, and promoting a post-petroleum based economy, is arguably one of the biggest and most urgent challenges facing our country today.

Politicians reacting to near doubling of fuel prices over the past several years have struggled to find workable solutions that will bring down prices and encourage domestic substitutes. Aside from threatening to levy windfall profit taxes on oil companies and trying to persuade producer countries to pump more oil, the primary policy response has been the promotion of large-scale subsidies for production of ethanol and biodiesel. The initial euphoria over agricultural-based fuels as the holy grail of American energy strategy has given way to concerns about the ensuing worldwide disruptions in the agricultural sector, the economic viability of corn-based ethanol and unintended environmental problems. The debate on biofuels will continue, no doubt, but it is difficult to make the case that biofuels are the pillars of a long-term energy strategy to lead America into the post-petroleum society.

After 30 years studying, debating and investing in challenges at the complex interface of energy use, environmental problems, technology development and economic prosperity, I have come to the conclusion that America needs a clear, bold energy strategy to guide it through the next four decades. The strategy must prioritize policies, public infrastructure investments and long-term technology development around one central theme. The theme is electrification – the pervasive use of electricity throughout the economy, and particularly the substitution of petroleum-based fuels with electricity as the core energy supply for transportation uses. A national energy strategy to promote greater electrification of the economy is the most practical, expedient and efficient path to achieving energy security for America, and ultimately of addressing global climate change challenges.

In the transportation sector, the urgency of the current oil crisis may appear to necessitate investing heavily in multiple substitutes to conventional petroleum. There is, in a democracy, always going to be a rationale for diversity and flexibility of alternatives.

Nevertheless, the most beneficial option – electrification of transportation – is actually the most flexible approach as well, and should be pursued most aggressively and with greatest clarity of purpose. When it comes to electricity generation, there are many "home-grown" sources: coal, natural gas, wind power, solar energy, hydropower, nuclear power, fuel cells, and eventually perhaps fusion and other sources. It is likely that America will need all of these in the future to meet burgeoning demand. By centralizing around the fundamental source of electricity, electrons, American policymakers can preserve ultimate flexibility. The free market, informed by future technical breakthroughs and conditioned by the regulatory process, can determine the optimum mix of generation sources many decades into the future, rather than the government seeking to select technology winners today. Moreover, electrification of the economy will allow America to maximize energy production at the same time we must radically reduce dependence upon one of the major sources of energy in our economy today – oil.

There is a role for continued and expanded use of natural gas as a transition fuel in the areas of electricity generation and domestic heating. Yet proposals to invest heavily in new infrastructure to shift America over coming decades from dependence on petroleum in the transportation sector to a reliance on natural gas ultimately present a Faustian bargain. The result will be to exchange one fossil fuel dependence for another, and divert an energy supply that could otherwise be used for other purposes, including home heating and electricity generation. The only way to break American dependence on fossil-fuels in the long run is to shift R&D and infrastructure investment sharply toward replacing internal combustion engines with electrically powered vehicles in mass transportation, commercial vehicles and automobiles. The seeds of change are already sown in each of these areas, with electrical power for transportation poised to expand market share on all fronts in coming years. However, continued efforts to push biofuels, or natural gas, as solutions for the transportation sector threaten to siphon off taxpayer money and divert public attention from accelerating the ultimate evolution of technological change toward electric vehicles.

This paper makes it abundantly clear that the dependence by our modern industrial and information technology economy upon electricity – the "accidental" addiction – will intensify in coming years. It demonstrates that there are major challenges and risks associated with this trend. Yet, from a national security and environmental quality perspective, intensifying electrification should be encouraged by public policies as one of the most important steps toward weaning America of its century-long addiction to petroleum-based energy supplies.

In addition, with the gradual elimination of petroleum fuels in transportation, America will be able to tackle the other major threat posed by fossil fuel use – global climate change – from a long-term, step-by-step perspective that has eliminated the national security and balance of payment threats presented by oil. Coal as a fuel for electricity generation must be cleaned up or eliminated by 2050. Many steps can be taken with pricing and regulatory policies in coming years, and technological breakthroughs can be fostered with long-term investment in R&D. Every year, more renewable energy generation can be added to the electricity generating capacity of America, both in large scale as generation stations for the grid, and in decentralized units for local and off-grid uses as distributed generation. This is the core of a national strategy for reducing greenhouse gas emissions in America without increasing national security threats or undermining the economy along the way.

With electrification established as the cornerstone of a New American Energy Strategy, state and national policymakers can hone a system of public investments, incentives and regulations designed to promote twin goals of greater energy efficiency and cleaner energy generation from cradle to grave of the electricity cycle. These measures should include:

- requiring cleaner sources of electrical power generation, including cleaning up coal that is burned, even while transitioning away from it over coming decades, deploying greater percentages of renewable electricity generation, addressing challenges of cost and nuclear waste in nuclear power;
- emphasis on recycling of gaseous emissions and waste heat recovery for on-site industrial electricity generation and thermal inputs;
- increased efficiency in the grid transmission and distribution of electricity;
- dramatic improvements in efficiency by electricity end-users in residences, commercial space, industry and transportation;
- transition to an electricity based transportation infrastructure, including public transport and electric vehicles;
- intense focus on battery and storage technologies for greater flexibility and mobility by electricity users;
- and, introduction of decentralized and distributed generation systems for electricity at the point of use.

All of these R&D and investment challenges are eminently addressable over the next 20 years. In the transportation sector, the technologies exist today to shift urban mass transportation systems decisively in favor of electrically powered trains, light rail and buses, as Europe has demonstrated clearly. American freight and passenger railroads could run all-electric with a decade of additional investment. In the automotive and trucking segments, technological progress is accelerating in the two key areas necessary to bring on the age of electric vehicles: batteries and drive trains. It is now reasonable to see electric vehicles – starting with small, city-oriented cars, delivery vans, and cabs in the next several years – expand into the mainstream transportation sector and grow to 25% or more of all vehicles by 2020. This transition could be accelerated by major policy initiatives from states and the national government. During this period, the continued electrification of the economy, coupled with continued utilization of the natural gas pipeline infrastructure to augment energy needs, could significantly reduce our dependence upon gasoline and other petroleum based fuels. In addition, appropriate investments and incentives could push electricity generators to be cleaner, and electricity users to be more efficient, year by year.

Since its founding in 1990, Global Environment Fund has tracked new market opportunities created by growing demand for cleaner and more efficient technologies. Our investment teams have provided growth capital for emerging business enterprises around the world that are deploying new technologies, creating new industries, and providing traditional pollution-intensive industries a way to lighten their energy and environmental footprints. Today we sit at a significant point in the evolution of technologies related to energy, in particular, and in the complex markets surrounding them. GEF views the coming decades as ones that will demand both the commercialization of new technologies and the deployment in much larger scale of technologies that have long been in gestation. The GEF Clean Technology investment team has developed its strategy for identifying new investments that take advantage of impending change in the energy industry. This strategy, borne out over GEF's experience through several cycles of long-term private investments, targets rapid application of existing, evolutionary technologies more than long-term bets on revolutionary, displacement technologies. With GEF's broad experience and success over the years, we are poised not only to participate in today's market but to be a significant force in propelling future change.

Seeking to understand at a deeper level one important but quiet dynamic – the economy's increased dependence on electricity – and to help GEF better track emerging companies taking advantage of the related market opportunities, the firm asked GlobalSmartEnergy to prepare this white paper. Even though we view the continued transition to an electrified economy as highly desirable for economic efficiency and environmental reasons, as noted above, we asked GSE to look deeper into some of the pitfalls and risks associated with this shift. If we advocate a shift to favor electricification on national security, balance of payments and environmental grounds, we feel equally a need to examine the roadblocks and danger points of such a program.

As this paper shows, the developed world is already irreversibly dependent on electricity. Over the last century, electricity in America went from a novelty to a necessity, and as the rest of the world develops, it is following the trends America has set. A major rise in world population, an increasing demand for electricity, and an increased use of appliances and consumer products are all behind this reliance. The U.S. Energy Information Administration predicts that, even with business as usual, electricity growth will cause worldwide generation to nearly double by 2030 – and require the equivalent of 25,000 additional 500MW coal-fired power plants to get there. The electricity dependent world means that reliable electricity functioning is necessary not just for our computers and cell phones but also critical societal needs like national security, finance, health and medicine, transit, and education.

Our electricity system is a huge system of interconnected parts, and if one of the pieces is not synchronized or breaks, the losses can be massive or even grind the entire system to a halt. Factors like antiquated electricity grids, the destabilizing effects of deregulation in the electric industry, demand for real time pricing, and the pressing need to increase efficiency are all encouraging innovation in the electrical sector. It is estimated that 60% of the current electrical equipment needs to be replaced in the coming decade. There now exist many "smart technologies" that can reduce system vulnerability rather than adding to it. In addition, strides are being made towards common standards that enhance technical and informational operability of the grid.

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. It is time for American policymakers to recognize that a concerted energy strategy centering on electrification is the pathway toward a more efficient, less polluting economy of the future. Our country's efforts to increase global economic competitiveness and achieve long-term reduction of greenhouse gas emissions both depend upon greater use and increased efficiency of electricity for transportation and industry. Even so, without major new investment in electricity sector infrastructure, our country will face energy shortages, power disruptions and blackouts on a grand scale in the decades to come. The good news is that technologies already exist, or are rapidly evolving, to meet all the challenges outlined in this paper necessary to sustain the electricity grid of the future.

This paper represents the outcome of a continued relationship between GEF and GSE on SmartGrid and electricity, an association we have benefitted from and look forward to continuing. We are very grateful to Global Smart Energy specifically Jesse Berst and Philip Bane for sharing their insights and expertise with GEF and our investors.

Introduction

Unnoticed by most, the developed world has become utterly dependent on electricity, for its lifestyle, its security and its prosperity. This dependence forces us to rely on:

- Dirty, coal-fired power plants
- Aging, outmoded grids that are stretched to the limit
- Regulated monopoly utilities with few incentives to innovate or modernize

Our accidental addiction also makes us susceptible to many risks, including:

- Severe weather and natural disasters
- Terrorist attacks on vulnerable centralized facilities
- Small mistakes that can ripple into major outages (as occurred in the Northeast Blackout of 2003)
- Market manipulation (as made infamous by Enron)

Even as this addiction has been taking hold, the electric power industry has undergone a quiet "revolution by evolution" as it converts gradually to a digitally controlled smart grid.

These two trends are now meeting. The appetite for electricity is exploding just as we are gaining new and better ways to deliver it. Put simply, the problems brought about by the first trend are creating demand for the solutions emerging from the second. This convergence is unleashing new products, new business opportunities and new markets of global proportion.

"Even though there are hurdles ahead and it may start a bit slow for some, we anticipate that retooling the grid will be an enduring trend," said the Stanford Group Company in its April 2008 report *New Electric Trends*. Indeed, the renewal and reinvention of the electric power infrastructure is one of the largest business opportunities of this new century. It will play out over the next two decades in virtually every part of the world. We hope this report will provide a useful map of the new terrain.

How This White Paper Is Organized

This white paper explains how two forces are colliding to reshape the worldwide electric power industry.

Section One, **Accidental Addiction,** introduces the first force. It explains the extent of our dependency, the reasons behind it and the serious (but largely unappreciated) vulnerabilities that result.

Section Two, **Revolution by Evolution,** explains the second force. The electric power infrastructure is moving away from the one-way electromechanical system pioneered by Thomas Edison. It is quietly morphing into a two-way digital network. This new smart grid resembles the Internet and the telecommunications networks in its ability to deliver brand new services in brand new ways.

Section Three, **Electroeconomics,** outlines likely business opportunities from the intersection of these two developments. It explains the five evolutionary forces that are shaping the market; reveals three areas of special diligence; and outlines more than a dozen emerging areas.

ACCIDENTAL ADDICTION: The Exploding Demand for Electricity

The developed world is irreversibly dependent on electricity. This addiction is happening "accidentally," as an unintended consequence of forces such as population growth, electrification and computerization. Taken separately, those trends did not seem momentous. Taken together, they are the unstoppable drivers behind the coming transformation of our electrical power infrastructure.

This section will document the extent of our addiction; present the factors moving us to even greater dependency; and explain the repercussions, both negative and positive.

Our Hidden Dependency

During the last century, the United States quietly underwent a change with profound implications. Electricity went from a novelty to a convenience to an advantage to an absolute necessity. Despite the headlines about our addiction to oil, we are even more dependent on electricity. We need it every day, all day. We need it for our most important functions. And we need more and more and more of it, with no end in sight.

One way to grasp the enormity of the change is to examine the numbers in the table below. They document a few of the shifts that are combining to create an Electricity Economy. **(Table 1.)**

Table 1: Examples of Electricity Growth Trends

Category	1950	2000	2050 (est.)
World Population [a]	2.56B	6.22B	8.29B
Electricity usage [b,e,f]	2.06 TW	3.80 TW	6.99 TW
Electricity as % of total energy [b,e,f]	10.4%	25.3%	33.7%
Televisions [c]	0.6B	1.4B	1.9B
Personal computers [g,h]	0	500M to 1B	6B to 8B
Cell phones (U.S.) [i]	0	0.8B	5B
Electric hybrid vehicles [k]	0	55,852	3,151,439

B = billion M = million TW = TeraWatt

Because it has taken place so gradually and because it is the sum of many smaller parts, this fundamental shift has gotten little attention. The chart below shows how a small, unnoticed change can have large impact over time. **(Figure 1.)** The Energy Information Administration (EIA) predicts that worldwide electric power generation will grow 2.4% a year between 2004 and 2030. Compounded over that period, this small annual increase will cause generation to nearly double by 2030 – from 2004's 16,424 billion kiloWatt hours (kWh) to 30,364 billion kWh by 2030.

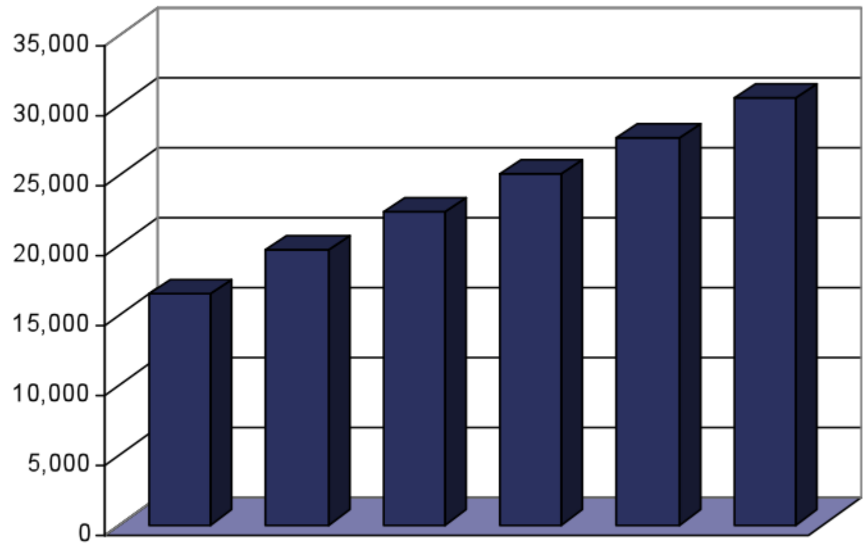

Figure 1: In 2007, the Energy Information Agency predicted that worldwide power generation would climb 2.4% per year from 2004 to 2030, nearly doubling in that period.

To put that growth in concrete terms, the world will need the equivalent of 25,000 additional 500 MW coal-fired power plants. Think about building 25,000 more power plants by 2030. Think about the amount of capital required; about the wires needed to transmit and distribute the power; about the impact on the environment if many of those plants use coal.

The military understands the importance of electricity. Electric power plants are one of the early targets in an air war. But neither the business community nor the general public has noticed that they rely so heavily on electricity that their worlds will grind to a halt without it. Our dependency is well beyond the point of no return. And powerful forces are at work to increase our dependency, as we will see in the next section.

Feeding the Addiction: The Forces Driving Continued Electrification

The electricity economy is far from its peak. In fact, three powerful trends are accelerating its growth. The first is the population explosion – the growth in the number of people needing electricity. The second is the "electrification of everything" – the growth in the number of devices that require electricity. And the third is "expectation inflation" – the growth in the sense of entitlement that turns electrical conveniences into essentials demanded by all.

The Population Explosion

Worldwide population growth has been well documented, but it will pay to remind ourselves of the astonishing increase expected in the next decades. The chart below graphs the trend line and shows the difference between developed and developing countries. **(Figure 2.)**

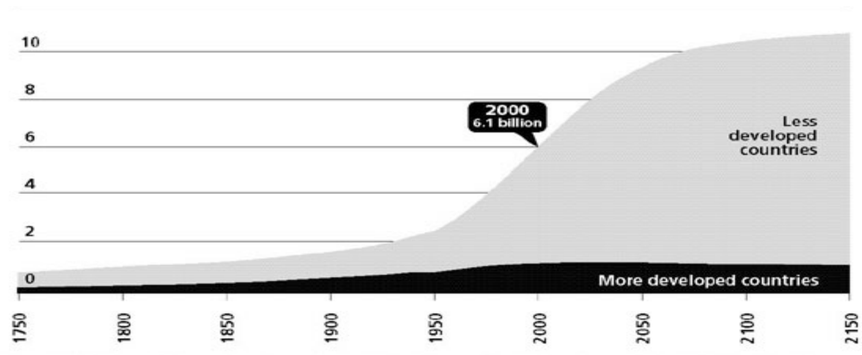

Figure 2: World Population Growth. The population explosion is a major reason for the increasing need for electricity. Most of the growth is occurring in the developing world. Source: UN World Population Prospects, 1998.

This population growth is fueling the growth in electricity demand. For example, electricity generation in North America is projected to grow 1.5% annually from 2004 to 2030, less than half the rates of China and India. **(Figure 3.)**

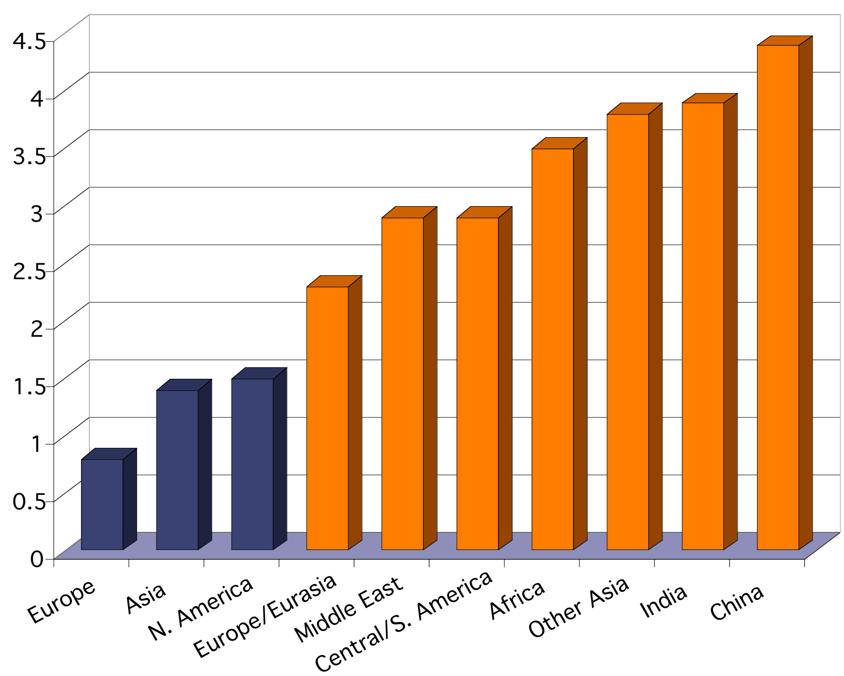

Figure 3: Annual Percentage Growth in Electricity Generation by Region, 2004-2030. System for the Analysis of Global Energy Markets, EIA, 2007.

If population growth were the only force at work, we would still see a big jump in the demand for electricity. But the trend is further amplified by the growth in per capita consumption. The developing world is rapidly catching up to the electricity-hungry lifestyle of the industrialized world. The chart below illustrates this trend. Notice how South Korea caught up to Japan and Germany in only 20 years. But South Korea has only 47 million inhabitants. Now imagine the effect of similar shifts in China, with 1.5 billion people and India, with 1 billion. **(Figure 4.)**

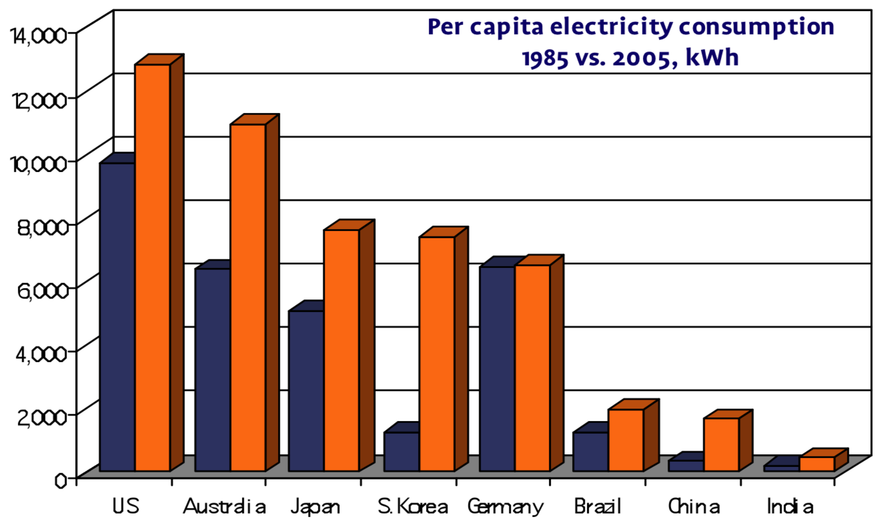

Figure 4: Per capita electricity consumption in kwH; 1985 (blue) versus 2005 (orange). Galvin Electricity Initiative, 2007.

The Electrification of Everything

At the same time population is skyrocketing, we are finding more and more ways to use electricity. Consider these examples gleaned from the U.S. Census Bureau (2005) and the U.S. Department of Commerce.

- In 1950, less than 1% of U.S. households were heated by electricity. By 1990, the percentage had grown to 30%.
- In 1950, no U.S. household had a microwave oven. Today, they are found in 95% of U.S. households.
- In 1950, no U.S. household had a computer. By 2003, the number had reached nearly 62%.
- By the end of 2007, more than 50% of all U.S. households owned at least one high-definition television. Changing from a standard TV to a larger plasma TV uses two to three times more energy.
- In the developed world, demand for electrical appliances surged 48% during the 1990s.

The table below shows just some of the important new uses for electricity that have appeared in the last half-century. And the growth is accretive. That is, we continue to use electricity for the old purposes even as we add new uses. **(Table 2.)**

Table 2: Additional Uses for Electricity

Sector	1950s	1970s	1990s	2010s
Industry	Lights Motors	Lights Motors	Lights Motors Process Control	Lights Motors Process Control Robotic Manufacturing Electronic "Vision"
Retail	Lights Refrigeration	Lights Refrigeration Air Conditioning Cash Registers	Lights Refrigeration Air Conditioning Cash Registers Card Processing Scanners	Lights Refrigeration Air Conditioning Cash Registers Card Processing Scanners RFID
Business	Lights	Lights Air Conditioning Mainframes	Air Conditioning Personal Computers Laser Printers Computer Networks Cell Phones Data Centers	Air Conditioning Personal Computers Laser Printers Computer Networks Cell Phones Data Centers Integrated Supply Chain
Finance	Lights	Lights Air Conditioning Mainframes Electronic Transfers	Lights Air Conditioning Mainframes Electronic transfers ATMs Online Trading Online Banking Data Centers	Lights Air Conditioning Mainframes Electronic transfers ATMs Online Trading Online Banking Data Centers Electronic Exchanges
Health Care	Lights	Lights Air Conditioning Diagnostics Patient TVs	Lights Air Conditioning Diagnostics Patient TVs Monitoring gear Physician Computers	Lights Air Conditioning Diagnostics Patient TVs Monitoring Gear Physician Computers Electronic records Tele-medicine
Home	Television Radio Record Player Refrigeration	Television Radio Home Stereo Refrigeration Hair Dryers Dishwashers Air Conditioning	Television Satellite Radio Home Stereo Refrigeration Hair Dryers Dishwashers Air Conditioning Home Security Home Theater Video Games Internet Wi-Fi Networks	Television Satellite Radio Home Stereo Refrigeration Hair Dryers Dishwashers Air Conditioning Home Security Home Theater Video Games Broadband Internet Wi-Fi Networks Digital Cameras Portable Players Home Automation

Two key developments have driven electricity into every facet of our lives – motors and microprocessors. During the second half of the last century, electric motors became small and cheap. As a result, they appeared in a wide range of applications, from refrigerators to dishwashers to hair dryers to air conditioners to the hard disk drives inside computers.

Then, during the 80s and 90s, the microprocessor became small and cheap. The first result was the computer revolution. Although estimates vary widely, most people agree that there are at least 500 million PCs worldwide, and the number could easily be twice that many.

Increasingly, those computers are massed into huge data farms, or linked together into "supercomputers." In 2008, the *Washington Post* reported that Dominion Virginia Power already had 22 computer data centers, with 24 more on the way. According to Dominion, those data centers are typically the size of a small Wal-Mart, but use an astonishing 25 times more electricity.

In 2007, Lawrence Berkeley National Laboratory reported that the electricity used by computer servers in the U.S. had doubled in the five years between 2000 and 2005. The Environmental Protection Agency released a similar report that same year, which found that servers were already consuming more electricity than all the nation's television sets combined. Even taking into account attempts to improve efficiency, the EPA estimated the power consumption of servers would nearly double by 2011 to more than 100 billion kWh, representing a $7.4 billion annual electricity cost at today's rates.

But the microprocessor isn't just about computers and server farms. It is increasingly about "invisible ubiquity." Microprocessors are being embedded into everyday life; from cars to hotel room door locks to automatic faucets to MP3 players. They are embedded into manufacturing as robotic welders, automated assembly lines, and process controllers. And they are increasingly part of our infrastructure as digital switches, remote sensors, digital relays and smart meters.

The vaunted "digital" economy is really an *electricity* economy. And we don't just need *more* power because of computerization. We need *better power* as well. Digital devices require high-quality electricity that is free of glitches. Even a micro-momentary sag or spike can disturb a sensitive measuring instrument, shut down an automated factory line, or trip up a personal computer. As we'll see when we look at the markets created by the electricity economy, many of the new opportunities revolve not around the quantity of power, but around its quality – its availability, reliability, measurability, controllability, and stability (absences of spikes and surges).

The developments described above – the cheap electric motor and the cheap microprocessor – are behind the deep and growing electrification of our world, including:

- **Finance,** from ATMs to clearinghouses to electronic exchanges
- **Commerce,** from warehouse automation to cash registers to card-swipers
- **Manufacturing,** from computer-aided design to sensors to monitors to controls to robots

- **Leisure,** from television to video games to electric-powered, microprocessor-equipped toys (the average U.S. household owns 26 different electronic gadgets, according to the Consumer Electronics Association)
- **Agriculture,** from irrigation pumps to computers to microprocessor-driven harvesters to GPS applications
- **Medicine,** from digital thermometers to digital X-rays to electronic records to bedside monitoring to computers
- **Transportation,** from GPS receivers to engine control units to cars that run partly or completely on electricity

The magic of cheap motors and cheap microprocessors will continue to drive innovations we cannot foresee. If we were to return to this report in 20 years, we would most likely find that we had far underestimated the growth and importance of electricity. Transportation, demonstrates how likely we are to *under*estimate the pace of electrification. To date, cars and trucks have incorporated dozens of low-powered electric devices such as air bag modules, anti-lock brakes, electric locks, electric seat adjustments and so on. In the not-to-distant future, however, cars may run partly or completely on electricity and plug into the grid to recharge. **(Figure 5.)** Such a shift could create a step function, vaulting us to a new level of demand for electricity, just as computers did before.

Figure 5: The Chevrolet Volt concept car is designed to run purely on electricity for up to 40 miles. The company promises to begin delivery in 2010. Courtesy General Motors.

The Inflation of Expectation

The growth in population and the move to electrification are the fundamental drivers of the electricity economy. But that economy is also getting a boost from a psychological phenomenon. Television and the Internet have spread Western expectations all over the world. TVs, air conditioners and computers have changed from luxuries to essentials in the minds of most Americans and, increasingly, most Europeans. And that expectation inflation is occurring all over the world. As their incomes rise, the citizens of the developing world are setting their sights on electric-powered devices. Refrigerators and televisions are typically the first "splurges" when a family climbs to the lower middle class.

We can use air conditioning in the U.S. as an example, though the trend is similar for other appliances and other regions. In 1950, central air conditioning was available in some

American theaters and high-rise office buildings, but rare in single-family homes. Today, the percentage of single-family homes built with central air is 87% (and fully 99% in the South) according to the Air-Conditioning and Refrigeration Institute (ARI).

Fifty years ago, residential air conditioning was considered a luxury, even in the hottest regions. Today it is "standard equipment." The share of households with central air-conditioning rose from 27% in 1980 to 55% in 2001. The DOE says air conditioning now accounts for 16% of the average U.S. household's electricity consumption – the same as the *combined* figure for lighting, stereos, televisions, CD and DVD players, desktop computers and printers.

And now Europe has caught the bug. The International Energy Agency predicted in 2004 that Europe would see a four-fold growth in air-conditioned homes from 1990 to 2020. Asia and South America are following closely behind. Sophisticated consumer markets are burgeoning in the developing world. By 2020, 80% of middle-income consumers will live outside the industrialized world. Newly developing market economies in India, China and Eastern Europe have added an unprecedented two billion workers to the global labor pool.[2]

The growing energy intensity of the developing world explains why straight-line extrapolations greatly underestimate the future demand for electricity. We have a triple multiplier at work: more people, more devices, more desire. Population growth creates more consumers. Innovation gives them more ways to use electricity. Urbanization and rising expectations gives them more hunger for an electric-intensive lifestyle.

The Vulnerabilities of an Electricity Dependent World

Today we depend on electricity for basic needs such as food, water, shelter, communication, employment and health care. Those needs are served by infrastructures for food preservation, water treatment, heat and light, phone service, Internet, offices, factories, hospitals and emergency response, to name a few. Yet all of those essentials degrade or disappear without electricity.

Later in this white paper, we will talk about the inevitability of certain market opportunities. That likelihood results largely from the dire problems that occur when the electricity supply is interrupted. In other words, we can't afford not to upgrade our power system, as the examples below help to illustrate.

National Security

The U.S. Department of Homeland Security (DHS) has identified electrical power as a key sector for national security along with information and communications, banking and finance, oil and gas, rail and air transport, and water. Even momentary interruptions to air traffic control, private security, 911 response, police or fire operations can threaten the safety of the population. Although many of those systems have backup power for central operations, that backup does not extend to edge devices, nor is it adequate for multi-day outages.

Health and Public Safety

During an outage, elevators freeze between floors, traffic lights go dark and subways become pitch-black catacombs. Consider the East Coast blackout of August 2003. Despite having emergency generators, four of the 75 hospitals in New York City were temporarily without any electricity. The large number of patients requiring assistance due to the blackout caused a strain on both emergency medical services and hospitals. The city had to cope simultaneously with 1) the failure of multiple hospital emergency generators; (2) an upsurge in patients; (3) vaccine spoilage due to loss of refrigeration; (4) beach contamination from untreated sewage; (5) failure of steam systems for sterilizing equipment, (6) heat-related health effects and increase of food-borne disease; and (6) increased rodent population as a result of discarded perishables.

According to Pacific Northwest National Laboratory, the August 2003 blackout cost roughly $6 billion in total (and more than $1 billion in New York City alone, or roughly $36 million per hour for that one city).

Commerce, Industry and Finance

It is hard to overestimate how dependent our economy has become on electricity. This reliance is most apparent during a blackout. Stores can't sell. Factories can't produce. Banks can't process checks or credit cards. Restaurants can't keep food cold. Sewage treatment plants can't pump the waste. Knowledge workers can no longer use email and Internet.

Nor is the damage limited to catastrophic outages. Even minor interruptions and glitches can shut down automated factory lines and damage sensitive gear. Brokerages and financial services firms can suffer losses in the millions for every hour they are offline. **(Table 3.)**

Table 3: Hourly Downtime Cost

Cellular Communications	$41,000
Telephone Ticket Sales	$72,000
Airline Reservations	$90,000
Semiconductor Manufacturing	$2,000,000
Credit Card Operations	$2,580,000
Brokerage Operations	$6,480,000

American Power Conversion, 2002

A 2002 study by the Electric Power Research Institute concluded that outages and disturbances cost the U.S. economy a minimum of $119 billion annually. Other studies put the cost at $150 billion. The $150 billion figure is the equivalent of an August 2003 blackout every two weeks, all year, every year. Because it is spread out and "invisible" it gets little attention. But given that the nation's annual electricity bill is roughly $300 billion, $150 billion represents a "hidden surcharge" of 50% on top of the electric bill we pay already each month.

An Essential Infrastructure at Risk

Just when we need it most, forces are converging that could double, triple or quadruple the cost of electricity over the next decade. Among the challenges:

An Aging Power Grid

From the mid-1970s until the early 2000s, U.S. utilities spent very little to update and upgrade the transmission and distribution infrastructure that carries electric power from the generating plants to the customers. **(Figure 6.)**

Figure 6: The original North American power grid has been called "the most complex machine on earth" and the "greatest engineering feat of the 20th century."

The transmission system – the high-voltage portion that carries power long distances – has much in common with the Interstate Highway system. Both are roughly 150,000 miles. Both were begun in the Eisenhower era and largely completed by the 1970s. Both are essential to national security and prosperity. Both are seeing "traffic" that far surpasses what they were designed to carry.

But the Interstate Highway system has been upgraded and maintained at taxpayer expense. The transmission system gets upgraded only when an owner decides to take on the expense. In many ways, this is like requiring a homeowner to pay for the full cost of an Interstate that passes nearby, even though tens of thousands of others will benefit.

Partially as a result of this mismatch between who pays and who benefits, the U.S. transmission system was neglected for nearly 30 years. Picture the results if the Interstate Highway system had never been repaved during that period. It would have become impassable in some areas. Likewise, the transmission system became increasingly fragile and congested.

That system was never designed to ship large amounts of power cross-country. Yet bulk power transactions jumped 300% from 1998 to 2004. In 1998, 300 of those transactions were incomplete because of congestion. In 2004, 2,300 transactions were incomplete. Transmission losses, which occur partly due to congestion, have jumped from 5% in 1970 to 7.2% in 1995 to 9.5% in 2001.[4]

Congestion and lost transactions deny entire regions access to less expensive power. In 2006, according to DOE estimates, congestion cost electricity consumers an estimated $2 billion.

Now this deferred maintenance can no longer be put off. Updating and upgrading the grid will cost nearly $1 trillion through 2030 in North America alone.[5] David Owens, VP of Business Operations at Edison Electric Institute, puts it this way: "We're now confronting one of the most serious periods in the electric industry's future. We are about to spend

$1 trillion on infrastructure, our prices and costs are escalating, the American public is concerned about the environment and wants solutions now and we must change our behavior and embrace more aggressively energy efficiency."

A Carbon-Constrained Power Sector

The electric power sector produces roughly a quarter of the world's carbon dioxide emissions. **(Figure 7.)** As the world turns to ever-more-stringent carbon limits, coal-fired power plants will be placed under ever-more-severe restrictions. To gain a sense of this quandary, consider these two statistics:

- Coal-fired plants produce roughly one half of all electricity in the U.S.
- Carbon capture and sequestration – which is not yet commercial or proven – may raise the cost of electricity from coal plants 40-50% over today's rates.

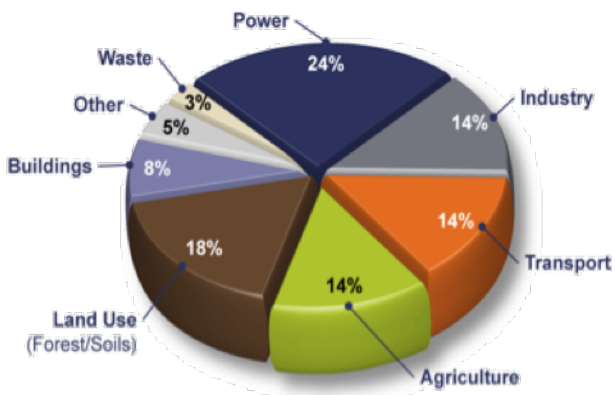

Figure 7: The power sector accounts for 24% of C02 emissions, according to the 2006 Stern Review on the Economics of Climate Change.

Rising Fuel Prices

Roughly three-fourths of all U.S. power plants rely on coal, natural gas or nuclear fuel. From 1999 to 2007, coal prices jumped 45% and natural gas 175%.[6] These increases are unprecedented by historical standards. Most experts believe prices will continue to skyrocket.

Rising Construction Costs

Just as we are recognizing the need to update and improve the electric power infrastructure, competition from China, India, Brazil, Russia and other growing economies is putting upward pressure on construction materials and costs. Copper prices, for instance, jumped 400% from 2003 to 2006.[7] Iron and steel were not far behind, with aluminum and cement also seeing significant hikes. Average U.S. utility infrastructure costs jumped 140-170% from 1991 to 2007.[8]

"Sticker shock" combined with not-in-my-backyard opposition is delaying construction of new plants and wires in many parts of North America. As a result, construction is not keeping up with demand. In 2008, the North American Electric Reliability Corporation (NERC) projected that electricity usage would grow nearly twice as fast as capacity. As a result, several regions could fall below their target safety margins within two or three years.

Rising construction costs are one reason more and more utilities are considering smart grid improvements. In theory, a smart grid allows them to pump more power through existing systems.

Mandated Renewables

Renewable energy is considered a good thing because it lowers emissions. Consequently, more and more countries and states are instituting renewable portfolio standards (RPS). These mandates decree that a certain percentage of the total power portfolio must come from renewables such as solar and wind. In most cases, the standards ratchet up, calling for a higher percentage each year.

But many renewables – wind, solar thermal and marine in particular – are typically located far from population centers. They put a strain on a long-distance transmission system that is already overburdened. What's more, most renewables are variable and intermittent. Intermittency places a great strain on the system. It requires a variety of methods to keep everything in balance as power surges up and down.

In the spring of 2008, for instance, the Texas grid suffered two serious incidents within two weeks. A sudden, unexpected drop in wind caused both problems. Although operators were able to prevent a blackout, such incidents are likely to become more common as renewables become a larger percentage of total power. Even hydropower is subject to variations due to changing water levels and wildlife protection measures.

Enlightened Customers

For decades, customers thought of electricity as a commodity that would always be in cheap, ready supply. They believed electric service was pretty much the same cost and quality everywhere. As they now learn more about electric power and its crucial role, customers are demanding power that is better, cleaner, greener and more reliable, all at the same time.

Big Rate Increases on the Way

The challenges cited above point to higher electricity prices – perhaps much higher than we are prepared to believe right now. Certainly we have a history of underestimating price jumps, particularly in recent years. For instance, the EIA has bumped its forecasts by 20% since 2006 due to rising fuel and construction costs. And those forecasts do not even take possible carbon caps into account.

Big rate increases could be a double-edged sword. On one side, spending for new infrastructure could be a hard sell when added to increases from other causes. On the other side, the smart grid may be seen as a way to minimize the construction of new plants and lines.

To this point, this paper has documented trends and problems – the galloping demand for electricity and the forces that threaten to make it more costly. In the next section, we will look at potential solutions, as embodied by the switch from the electromechanical grid pioneered by Thomas Edison to a next-generation, digitally controlled system.

REVOLUTION BY EVOLUTION: The Transformation of the Electric Power Infrastructure

Just in time for our rising dependence on electricity, the electric power infrastructure is being remade. Gradually, without much fanfare, it is being rebuilt from the inside out, with digital gear replacing the electromechanical equipment of the past.

This change is not based on radical, unproven breakthroughs. Instead, it involves the step-by-step application of existing technologies, many of which have already been proven in the telecommunications and computing sectors. This is not a rip-and-replace strategy, but a phased "revolution by evolution." It is much less about invention and much more about implementation.

This section will review the traditional way of delivering electrical power and the new approach that is taking its place.

The Traditional Approach to Electric Power

For roughly a century, the developed world has delivered electric power using the same basic four-step approach: 1) generate power in large, centralized plants; 2) step up the power to high voltages and transmit it to regional utilities; 3) step down the power to medium voltages to distribute it locally; 4) step down the power a final time to deliver it to customer premises. **(Figure 8.)**

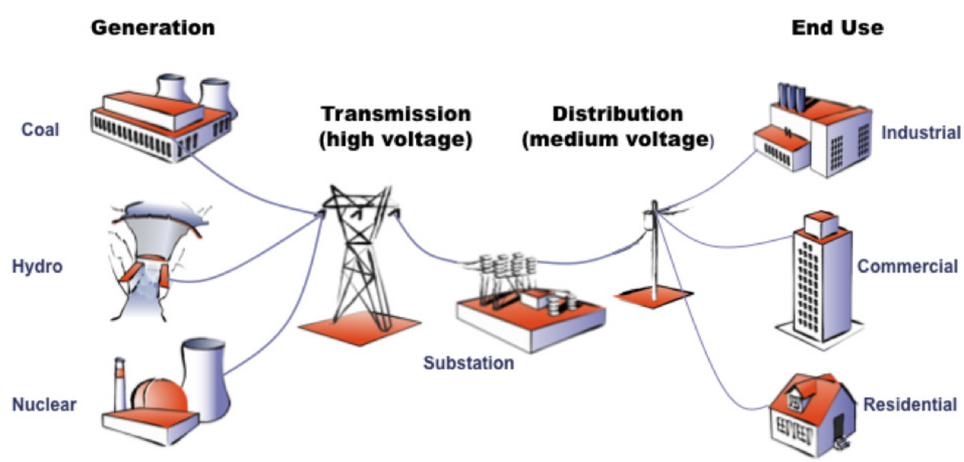

Figure 8: The "traditional" electric power value chain encompassed centralized **generation,** high-voltage **transmission,** medium-voltage **distribution,** and **end use** by industrial, commercial and residential customers.

But a 21st-century economy cannot be built on a 20th-century grid. The traditional approach has several characteristics that make it unsuitable to today's conditions. For one thing, much of the grid is still largely electromechanical, using physical switches and analog controls. This equipment is no longer up to the challenge of a world where bulk power is shipped hundreds or even thousands of miles, and where local utilities must coordinate constantly with nearby utilities and transmission operators.

For another, the grid is balkanized – divided into many small, semi-autonomous regions. The North American Electricity Reliability Council (NERC) divides the U.S. and Canada into 10 reliability regions with more than 150 control centers serving more than 3,300 utilities. **(Figure 9.)** Many of these entities still interact via clipboards and phone calls. There is a clear need for better "situational awareness." And for the kind of split-second coordination that only computers can supply.

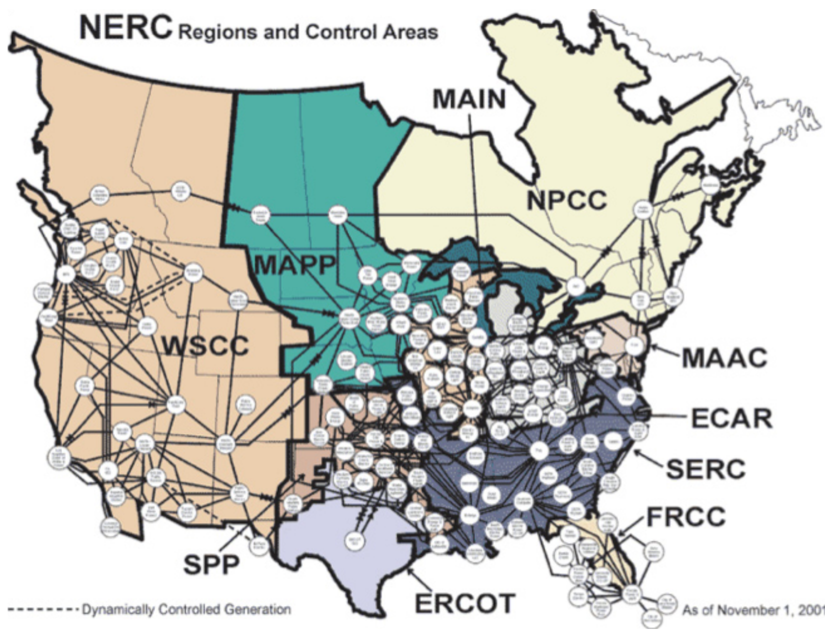

Figure 9: The U.S. and Canada are divided into 10 regions and more than 150 control areas. This fragmentation adds to the challenges of control and coordination. NERC, 2001.

Although suitable for the last century, the traditional approach to electric power cannot handle the changes that have taken place over the past 30 years:

- Huge increases in bulk power shipments from one region to another
- A shift towards distributed generation, which scatters many smaller power plants closer to customers – but which adds complications in control and coordination
- A shift towards renewables such as wind and solar, which add stress and complexity
- An increasing need to regulate and control the demand side, which adds yet another layer of complexity
- Much more stringent regulations for reliability, security and reporting that, once again, can only be accomplished with the help of computers.

The New Approach to Electric Power

The new approach to electric power adds computers and communications to the existing network. The transition is similar to the one that began two decades ago in telecommunications network, where digital equipment gradually supplanted analog approaches. For those familiar with computing and the Internet, the effect is to embed information technology into the existing network.

"As the power industry relies increasingly on information to operate the power system, two infrastructures must now be managed: not only the *Power System Infrastructure*, but also the *Information Infrastructure,"* explained the International Electrotechnical Commission in a 2005 security standards publication. "The... power system infrastructure has become reliant on the information infrastructure as automation continues to replace manual operations, as market forces demand more accurate and timely information, and as the power system equipment ages."

Most of the changes are taking place in the delivery infrastructure, where a new, so-called smart grid employs digital technology in three important ways:

- **Intelligent devices** monitor and measure what is going on
- **Two-way communications** allows those devices to talk to each other (and to the control center)
- **Advanced control systems** let computers make low-level decisions automatically while allowing human operators to visualize and control large areas from a central station

Intelligent Devices

Intelligent electronic devices contain three basic elements: a) electronic sensing and measuring to know what is going on; b) digital intelligence to make basic decisions on their own; and c) communications ability so they can talk and listen. They are used for things such as:

- *Remote operation* to allow operators to throw switches, isolate faults, switch feeders, and turn equipment on or off from many miles away
- *Remote monitoring* so operators know instantly what is happening inside substations and across long distances without the need to send out work crews
- *Smart measurement* and metering to know the exact quantity and quality of the power being used

Smart meters combine the three functions described above. A state-of-the-art smart meter shows just how much power was used and when it was used. Many of them can also remotely monitor power availability and quality, sending back a signal if the power goes down, so the utility knows instantaneously where the fault is and how many customers are affected. Many smart meters also allow the utility to remotely turn service on or off (for instance, when a new tenant moves into an apartment building) without the need to send out a lineman.

There are hundreds of other smart devices. **(Figure 10.)** Eventually, the electric power system will be monitored from end to end, from the generators to the transformers and substations to the lines themselves to the meters and right into the customer premise via smart thermostats. This end-to-end intelligence is already in place for the telecommunications and Internet networks, and it will occur in the electric power infrastructure as well.

Figure 10: Intelligent devices are proliferating throughout the electric power value chain, from digital relays that reside inside substations (left), to smart meters that sit on customers' walls (center), to communicating thermostats inside the premises (right). Courtesy SEL, Itron, Comverge.

Two-Way Communications

Smart devices don't add much value unless they can communicate. They can talk to each other in many different ways – over the Internet, over the power lines themselves, over cell phone networks, via satellite, and so on. In the real world, most smart grids use a mixture of communications methods. It matters less which method is used than which protocols are supported, since devices that use open standards can talk to each other over many different pathways.

This multiplicity of approaches is both a benefit and a barrier. It benefits utilities by giving them a wide range of choices. They can, for instance, use WiFi in dense urban environment and satellite for hard-to-connect commercial sites outside the metropolitan area and powerline technologies for rural regions.

But having many choices also creates confusion. There is no widely agreed default, "safe" choice. Because each method has pros and cons, there is no dominant system. Many urban areas have multiple communications pathways side-by-side, including cable, fiber, DSL, cellular, satellite, paging, WiFi and broadband over powerline. Each provider finances the full cost of its infrastructure, but often that infrastructure is used to only a fraction of its capacity.

The long-term key to lower costs is to share infrastructure, so that utilities don't have to bear the full cost of a single-purpose network. Indeed, the high cost of constructing a communications network has killed numerous smart grid and demand response projects. State regulators have been unwilling to pass the costs through to ratepayers. When communications and installation are factored in, costs can easily reach $500 per smart meter, putting them out of financial reach for many utilities.

In theory, sharing existing Internet or cellular systems would bring costs down. In practice, many utilities have concerns over security, universal access (for every utility customer) and priority (the ability to put their needs ahead of everybody else in the event of a power emergency).

Advanced Control Systems

Advanced control systems are the third leg of the smart grid stool. They help in several ways: by handling routine, split-second decisions automatically; by giving operators more visibility and control; by sorting through masses of data to uncover exceptions and problems; by using advanced algorithms to optimize the system; and many more.

The common factor is to use the power of computers to accomplish things impossible for human operators working alone. The Northeast Blackout of 2003, which affected 50 million people, took hours to build up. But once it broke out of its initial control area, it took only nine seconds to cascade from Ohio to New York – much too fast for human operators to react. That need for instantaneous reaction explains why one goal of the smart grid is "self-healing" – the ability to spot and isolate a problem early and route power around it. For example, when a fault occurs, a digital relay can trip the line before the damage spreads. What's more, it can alert the control room, so operators can take immediate steps. Many digital relays can even send information about what was going on just before the fault, to help with diagnosis. When the problem is over, the relay can be reset remotely.

The smart grid also expands visibility and control. Control centers can monitor entire regions, even gaining visibility into neighboring jurisdictions. New software for controlling the grid makes it much easier for operators to manage large areas and to spot problems early. In fact, some of today's smart software can predict problems in advance. Other packages can optimize the system to put as much power as possible through the lines while still maintaining safety margins.

Today, recovering from a major event is an arduous process. Restoration can require days of repairs, replacements, and reconfigurations. It often takes hours just to figure out the precise location and cause of the outage, since old-fashioned grids are largely "blind." A smart grid greatly improves restoration by feeding data from meters and sensors into geographical information systems. Operators can see instantly where problems are originating and which crews are available to assist.

It's great to recover quickly from problems. It's even better to prevent them in the first place. Today's systems provide little predictive insight. This is changing as analytical technologies provide look-ahead capabilities.

The Product Landscape

The table below lists representative products from all three categories. The list is not intended to be comprehensive or exhaustive, but merely to provide a few well-known examples from each area. **(Table 4.)**

Table 4: Representative Smart Grid Products and Services

Category	Product / Service	Description
Intelligent Devices	**Smart Meters**	The poster children for the smart grid. Smart meters can measure how much electricity was consumed *and when* (interval measurements). They can store that data until it is time to send it along. They can transmit the data, eliminating the need for a meter reader. And they can "listen" as well as talk. For instance, some smart meters can accept and store new time-of-day pricing information, provide readings on demand, or remotely connect and disconnect. Some can measure power quality along with power quantity.
	Advanced Sensors and Monitors	*Direct voltage and flow sensors* measure in real time, providing immediate notification of problems. *Power line monitors* measure sag and temperature of cables, spotting problems early and allowing lines to run closer to capacity. *Transformer monitors* measure key parameters that previously required an in-person visit. *Power system monitors* collect power flows, voltages and other signals for the control center.
	Digital Relays	Microprocessor-equipped relays not only protect equipment, they can report problems to the control center and give information to help diagnose the cause.
	Inverters and Balance of System	Convert, condition and control the power from renewables and other forms of distributed generation so it can be connected to the grid.
	IEDs (Intelligent Electronic Devices)	A blanket term used to describe solid-state electronics and digital gear inside substations. IEDs monitor, control and report on power quality, flow and substation conditions.
	Grid-Aware Equipment	Thermostats, switches and appliances that can be remotely controlled and/or that can report on their own power use.
Two-Way Communications	**Broadband Over Powerline (BPL)**	Using existing power lines to transmit data. Can be used to send signals for smart grid applications, to provide Internet access to customers, or both.
	WiFi and WiMax	The radio-frequency technologies used for wireless networking can also be applied to smart grid applications.
	Zigbee	Typically, Zigbee is used just in the house or neighborhood, and a faster method is used to collect the local data and "backhaul" it to the control center.
Advanced Control Systems	**Distribution Automation**	Remotely monitor and control operations formerly done manually at substations and feeders.
	Energy Management System (EMS)	Using data from monitors, sensors and meters, create a picture of the entire system for analysis, control and planning. Can apply to utilities, or to large users that need to monitor a factory, campus or high-rise.
	Geographic Information Systems (GIS)	The same technology behind Google Earth can be applied to electric power. GIS applications can map a utility's field assets (lines, substations, transformers, meters), show the location of outages, pinpoint work crews in real time and help with planning and optimization.
	Demand-Side Management	Reduces demand in response to an incident or request from a utility. Used in times of peak load to reduce demand until the grid can recover.
	Wide-Area Management Systems (WAMS)	Visualize and control large regions; often used in conjunction with the movement of bulk power over long distances.

Portions adapted from "The Emerging Smart Grid," Center for Smart Energy and Global Environment Fund, 2005

Benefits of a Smart Grid

The final section of this report outlines emerging investment themes. Those business opportunities arise from the benefits a smart grid can bring, benefits not available until now. The table below summarizes some of the characteristics of a modernized grid, which can lower overall costs while improving reliability and environmental protection. **(Table 5.)**

Table 5: Characteristics of Tomorrow's Smart Grid

Characteristic	Yesterday	Tomorrow
Generation and Storage	Dominated by central generation. Little use of distributed generation, renewables or storage.	Many distributed resources complement central generation.
Resiliency	Did not protect assets until a disruption (e.g. trips a relay after a fault). Vulnerable to terrorists and natural disasters.	Self-healing: Prevents many disruptions, minimizes impacts from the rest. Resilient with rapid response.
Optimization	Little integration between grid and asset management.	Deep integration of grid intelligence with asset management software.
Power Quality	Focus on reliability not quality.	Power quality a priority with a variety of quality/price options to choose from.
Market Empowerment	Limited wholesale markets, poorly integrated. Limited customer choice, no price visibility.	Robust, well integrated, computer-managed wholesale markets. Many choices, time-of-use pricing visible.

Adapted from "Characteristics of a Modern Grid," Modern Grid Initiative, 2006

Lower Costs. A smart grid allows greater use of existing assets, delaying or doing away with the need for new plants and new lines. For instance, experts say an upgraded grid can send 30% to 300% more electricity through existing corridors. A smart grid can allow demand response to substitute for new generation, often at one-third the cost of a new power plant. And it can allow design engineers to understand precisely where power is needed, so they can optimize designs, building only what is needed rather than overbuilding just in case.

Greater Reliability. A smart grid improves reliability in several important ways. For instance, it allows for "self-healing." The system performs continuous self-assessments to detect, analyze and mitigate problems. A smart grid also resists natural and man-made disasters. It deters cyber-attacks, detects physical attacks and isolates problems so they do not bring down the entire network.

Because a smart grid can minimize or eliminate blackouts and interruptions, it also removes a "hidden tax" from ratepayers. Blackouts, interruptions and power quality events add at least 30-50% to the cost of electricity, according to the Electric Power Research Institute. This hidden surcharge comes in the form of business interruptions, lost data, computer crashes and manufacturing shutdowns.

A smart grid can also lower costs by giving consumers more choice. Although giant industrial companies can negotiate special rates, most utility customers are faced with an any-color-as-long-as-it's-black choice. A smart grid makes it possible for utilities to offer many different rates, in the same way cell phone companies offer many different plans. Some business customers might choose a higher rate in return for guaranteed reliability. Some residential customers, on the other hand, might be willing to accept occasional interruptions for a lower rate. A smart, computerized utility can eventually offer multiple plans suited to the special needs of different groups.

Improved Environmental Protection. More and more states and provinces mandate utilities to generate a certain percentage of their power from renewable sources. Put simply, utilities will not be able to meet those mandates without a smart grid. All over the world, policymakers and utilities are waking up to the fact that they cannot connect, ship and control the green power they want without a modern, intelligent grid.

Barriers to a Smart Grid

Several barriers may delay the onset of the smart grid and slow the progress of emerging companies.

Perceptual and Educational Barriers

One of the biggest hurdles to grid modernization is lack of understanding. The electrical grid was one of the marvels of the 20th century, providing cheap electricity to an entire nation and giving the United States a competitive advantage. It was so dependable, in fact, that generations came to take it for granted. Few of us noticed that this all-important asset was rusting away.

Today, the bills for neglect and deferred maintenance are coming due. Yet few people understand what the grid is, how it works and how essential it has become. Since the 1970s, both our prosperity and our lifestyle have come to rest heavily on the grid. As explained in a 2007 white paper from the Modern Grid Initiative, far too few people realize that:

- Today's grid is vulnerable to attack and disaster. An extended blackout would be catastrophic to our security, economy and quality of life.
- Today's grid cannot address the security and economic challenges of the 21st century. It may lead to loss of jobs as work is transferred to regions with more reliable and economic grids.
- A modern grid will be more efficient and less costly.
- A modern grid will enable clean technologies and other options for addressing climate change.

Ratepayers and regulators still fail to understand *it does not have to cost more to do it right*. Some digital equipment costs the same or less as the electromechanical version it replaces. Even when digital equipment costs more upfront, it can pay for itself over time, via the benefits explained elsewhere.

What's more, the transition *does not have to happen all at once*. When a substation needs to be added anyway, it can be a smart substation with digital protection and communications built in. Later, as the utility adds additional smart equipment, that substation can link with it and with the central office. By contrast, if a utility installs old-fashioned equipment, it must later face an expensive replacement or retrofit to bring it up to digital standards.

The smart grid, in other words, is not a "rip-and-replace" strategy. Instead, it is "revolution by evolution." The grid can be modernized one piece at a time, as each component comes due for replacement or expansion. But this systematic approach only works if there is a roadmap and if state regulations allow utilities to invest today in modernized gear that has big payoffs tomorrow – something that is only now taking place, and only in selected parts of the world.

Policy and Regulatory Barriers

In the U.S., the Department of Energy has been running a GridWise research program since the early 2000s. The Energy Policy Act of 2005 contained numerous smart grid provisions, including mandates for states to study advanced metering and demand response. The Smart Grid Facilitation Act of 2007 was designed to "facilitate the transition to a smart electricity grid."

But regulations are not modernizing at the same pace as equipment. A patchwork of conflicting, confusing regulations makes it difficult and time-consuming for utilities and vendors, who must operate under a different set of rules for virtually every locale. PJM is a regional transmission operator that conducts business across 14 states. Five of those states still have regulations that technically make it illegal to participate in wholesale power markets and demand response markets – even though demand response is national policy at the federal level.

"Grid modernization has been chilled for more than a decade due to an uncertain regulatory climate," concluded the Modern Grid Initiative in 2007. "Each state is in a different phase of deregulation, state PUC's are inconsistent among themselves, and the interfaces between FERC and the state PUC's are not always clear and consistent."[9]

Barriers can also create big waves of progress when they are finally removed. As this white paper went to press, North Carolina was considering a rate case filing by Duke Energy that would give the utility the same rate of return for reducing demand as for increasing supply (building new generation). If that case is accepted, and if it is accepted across the U.S., it will drive a massive shift in investment, away from traditional generation and toward demand reduction strategies (and the smart grid technologies that support it).

Now that we have looked at the world's addiction to electricity and seen how new technology is reshaping the industry that provides that power, we can turn our attention to the new business opportunities arising from the intersection of these two global trends, as documented in the section that follows.

ELECTRONOMICS: Emerging Business Opportunities in the Electricity Economy

To this point, we've documented the problems – our growing addiction to all things electric and our resulting dependence on an outdated, vulnerable electric power infrastructure. We also looked at some potential solutions as embodied by the smart grid – solutions that could reduce our danger, lower our costs and usher in a wave of new products and services.

Now it's time to consider what those trends mean for investment and business. Economics studies the production and distribution of goods and services. We can define "electronomics" as the study of new goods, new services and new ways of distribution in the rapidly transforming electric power sector. As we will explain in more detail, the industry is moving:

- **Beyond traditional generation,** such that demand becomes supply, externals become internals and centralization ultimately gives way to distributed microgrids
- **Beyond traditional transmission & distribution,** such that meters become dashboards, dependence transforms to interdependence and data becomes intelligence
- **Beyond traditional business models,** such that quantity makes way for efficiency, commodities become specialties and point solutions become platforms

Investors who get it right will be tapping into an enormous market. The Brattle Group says that North America alone will require nearly $1 trillion in new transmission & distribution investment from 2008 to 2030, *not counting what will be required to meet future climate change rules*. $1 trillion is a very large number. Yet transmission & distribution is only part of the investment landscape and North America is only part of the global equation. In fact, North America is not even the fastest-growing region. The rest of the world will spend at least twice what North America spends on generation and grid upgrades.

Before we begin our discussion of investment themes, it will pay to consider a) the large-scale "evolutionary" forces that will shape the sector's growth and b) three areas of special diligence.

Five Evolutionary Forces

High-tech markets go through predictable phases as they grow to maturity. Since the electricity sector borrows heavily from the computer, Internet and telecommunications worlds, it is no surprise that those same forces apply. The opportunities sketched out at the end of this section will be tempered and shaped by five tendencies:

- Centralized to networked
- Passive to transactive

- Customized to standards-based
- Vertical to horizontal
- Permanent whitewater

Centralized to Networked

If we consider the evolution of high-tech sectors, we see that smart devices typically start out in the "center," then migrate to the edges as they get smaller and cheaper. Eventually, they create a true network with intelligence scattered throughout. **(Figure 11.)**

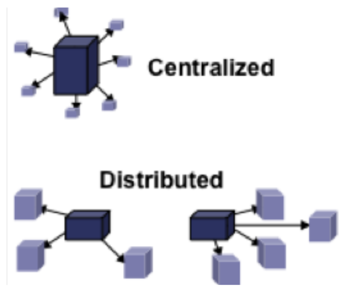

Figure 11: Like the computer world before it, the electric power infrastructure is moving from centralized to distributed to networked.

In the computer industry, the progression was from the centralized mainframe world to the dispersed client-server architecture to today's vast Internet. In the telecommunications world, intelligence resided initially in the central switching facilities of the phone companies. Today, devices such as the iPhone are small computers in their own right and we are seeing an explosion of new uses for mobile phones.

In a similar fashion, smart devices are becoming pervasive in the electric power sector, from generation source all the way to the customer premises. **(Figure 12.)**

Figure 12: Smart communicating devices can be embedded all along the value chain. They can monitor and dispatch generation; measure voltage, power flow and line sag; report on the condition of expensive transformers; protect vital circuits; meter power; and more.

Passive to Transactive

As intelligence migrates out, end points gain the processing power to do useful work. Typically, a sector goes from passive to active to interactive and finally to "transactive," since the ultimate economic goal is to enable transactions. It is not necessary for a human to be involved for a transaction to take place, as with today's automated stock trading programs. Likewise, on tomorrow's smart grid, most "transactions" will be between computers and devices that have been pre-programmed with rules and guidelines.

Media provides an easy-to-follow example. **(Figure 13.)** Print was passive, television became interactive and the Internet was also interactive. But the Internet did not enter its explosive growth phase until it became "transactive" – until technology enabled companies such as Amazon to sell online.

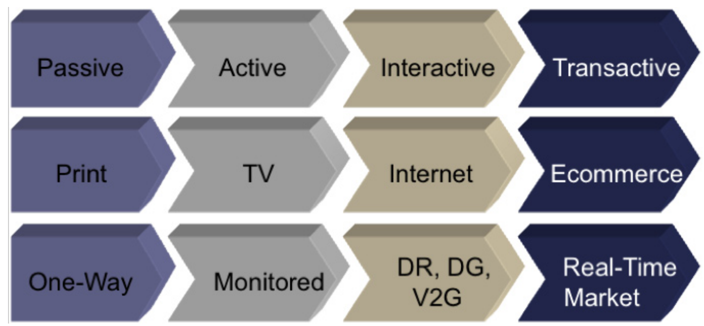

Figure 13: High-tech sectors tend to move from passive, to active, to interactive, to "transactive." Media (center arrows) went from print, to TV, to Internet, to ecommerce. Electric power (bottom) is trending from one-way, to monitored, to distributed, to a real-time market.

In the retail world, cash registers have gone from passive (mechanical) to active (calculate tax and totals) to interactive (scanners and card swipers) to transactive. Today, shoppers in places as diverse as Home Depot and Burger King can use touch screens to ring up their own purchases and make their own selections, handling the entire transaction without assistance from a cashier.

The same transition is underway in electric power. More and more intelligence is migrating to meters and home devices. Ultimately, they will "transact." For instance, meters and appliances will note the current price of power, turning devices off during expensive peak times and on again during off-peak hours (essentially "selling" their demand response to the utility).

Customized to Standards-Based

High-tech markets start out in chaos, with multiple approaches and technologies. Gradually, standards emerge that allow things to plug and play together. One example comes from personal computing, where the creation of standards such as DOS and Windows unleashed an explosion of choice for consumers and led to a rapid decline in prices. Until then, each computer program had to be written for one particular customer using one particular computer.

Likewise, Web 1.0 was made possible by HTML and other standards and the move to Web 2.0 is enabled by standards for "widgets" that can be mixed and matched on any site. A similar evolution is gaining force in the cell phone world, where companies such as Google and Microsoft wish to create standard platforms to enable any phone to work with any provider.

Until recently, electric power utilities have been able to deflect this powerful tendency. Until recently, almost all utilities specified hardware and software that was custom-tailored to their preferences, despite the extra time and cost. Today, they are gradually coming to realize that standards:

- Give them more power over vendors (since they can freely mix and match products)
- Increase their choices (since they can choose from a wide range of plug-and-play options)
- Decrease their costs (since competition lowers prices)

Important standards are already in play in the electric sector, but some observers continue to underestimate their long-term impact. Not only will standards enable today's vendors to sell much more widely, they will also enable companies from adjacent industries to enter this market. For instance, a smart meter is nothing more than a measuring device attached to a microcomputer attached to a communications pipe. Companies such as Hewlett-Packard, Dell, Microsoft and Cisco know all about computers and communications. It's no wonder that many computer and telecommunications companies are now beginning to explore the electricity sector.

Vendors who adapt their products and sales strategies to open standards will ultimately prevail. Those who try to maintain a closed, proprietary system may stave off the invasion for a while, but will ultimately succumb.

Vertical to Horizontal

The forces described above tend to "liberate" a market, allowing many different competitors to enter at many different levels. This causes a move away from vertical integration to horizontal competition. In the 1970s and early 1980s, the computer industry was dominated by vertically integrated giants, who made everything from the enclosures to the chips inside to the operating systems and the applications.

The advent of the microprocessor heralded a new era of "horizontal" competition. Soon there were multiple competitors at all levels: multiple chip makers; multiple operating systems; multiple applications.

A similar trend is underway in the electric power sector. This trend has been slowed by regulations in the U.S., Europe and elsewhere that favor vertically integrated monopolies. Despite those countervailing forces, it is clear that the electric power sector will continue a gradual march towards horizontal competition, with multiple choices at each level. This "deconstruction" will be earliest and most obvious where it involves small, easy-to-replicate hardware (such as metering and networking). It will be slower to appear in those areas that involve larger, complex systems (such as substations and major software systems).

Horizontal competition may be slowest to appear in the sale of power itself, where certain regions will continue to resist retail electricity and consumer choice, preferring the single-choice regulated monopoly that was the dominant model of the last century. Yet even at that level, the change is indisputably underway. Many countries and states are well down the road towards the separation of generation, transmission and distribution into separate entities.

Permanent Whitewater

High-tech industries are in constant flux, with new innovations making last year's favorites obsolete. As the electric power sector morphs into a high-tech market resembling telecomm and computing, it will likewise enter a long period of non-stop reinvention.

This upheaval will be exacerbated by the electricity economy and the urgency it creates. Years of neglect combined with growing populations combined with the electrification of everything combined with global competition are making it obvious that an overhaul is essential. This attention will lead to increased business and political pressure to update.

After a half-century of business as usual, utilities will find themselves subjected to constant changes – policy changes, regulatory changes, technology changes, business model changes. Nor is the pressure likely to let up for at least a decade. And some old-line vendors are just as calcified as the utilities. Companies such as General Electric, Siemens and ABB are now reinventing themselves to compete with nimble young companies that resemble Internet startups in their ability to adjust to changing conditions.

Three Areas of Special Diligence

The balance of this section will be devoted to investment themes that are likely to play out over the next 5-10 years. It is fitting, therefore, to remind readers of several unique requirements. The electricity sector requires the same technical, financial and managerial diligence as any other high-tech market. It also requires additional care and caution in the three areas below:

Policy Diligence

As Morgan Stanley Research said in "The Economics of Climate Change" (October, 2007): "Climate change... will require enormous government policy action. Understanding and anticipating government decisions correctly will be key to investment success." Virtually all climate change policies will have a major impact on the power sector, which is the single largest contributor to climate change.

The drawing below is an analogy, not an attempt at numerical accuracy. **(Figure 14.)** But it illustrates the nature of the challenge. Policy always lags behind technical change. For instance, the speed at which countries adopt carbon emissions policies – and the degree to which they target electric power producers – will strongly influence the speed and direction of growth. Likewise, the degree to which they adopt smart grid initiatives will strongly influence which areas grow rapidly and which lag behind.

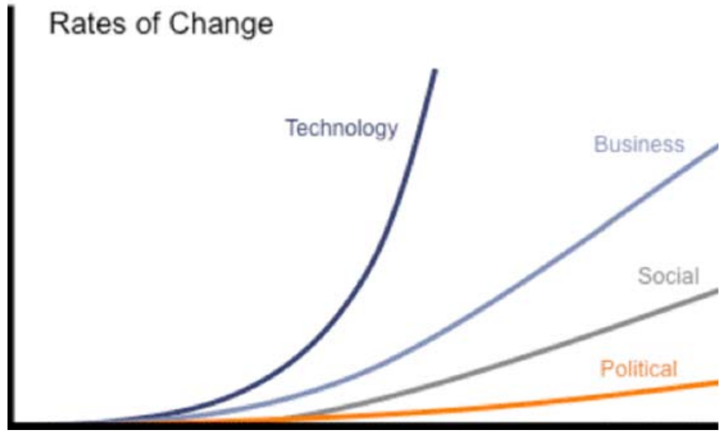

Figure14: Political change always lags behind technology.

Even after the technologies have been perfected, it may be policy that determines how fast they can be adopted.

Regulatory Diligence

Policymakers create the rules. Regulators enforce them, at least in the U.S. where most utilities still operate as regulated monopolies. Balky state regulators can delay or ignore federal guidelines, as has been the case many times in areas such as deregulation, transmission siting, reliability measures, smart meters and demand response.

"Progressive" regulators in states such as California and New Jersey have pushed utilities to move forward quickly. Elsewhere, a "traditional" approach has slowed adoption. Many successful Smart Grid startups and progressive utilities have "hop-scotched" around the country to friendly jurisdictions while ignoring regions where regulators were not yet supportive. This localized, "warlord" approach to regulation is one of the reasons the U.S has fallen behind other countries in grid modernization. It is a significant investment consideration.

Customer Diligence

As you might expect from regulated monopolies, most electric power utilities have a risk-verse culture. A recalcitrant utility can fend off change for years or decades, even in the face of demands from customers and mandates from policymakers. Grasping the full extent and power of utility reluctance can be a challenge for high-tech companies accustomed to adoption curves similar to the drawing below. **(Figure 15.)**

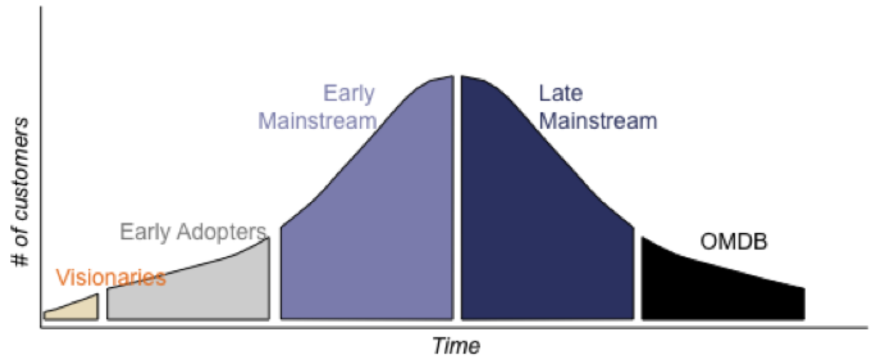

Figure 15: The "standard" customer adoption curve, showing chasms between different groups. OMDB stands for "over my dead body," one term for technology laggards.

Any company that hopes to succeed in this space must understand utility sales cycles, buying triggers and mandated processes. For instance, larger utilities are often required to go through a lengthy public process to buy new technology, one that quite often draws protests from consumer groups arguing that the utility is wasting money. Vendors must be prepared to identify utilities that are ready to act while skipping over utilities where internal factions have set up roadblocks. And they must have the patience and financial resources to wait out an adoption curve that often resembles the drawing below. **(Figure 16.)**

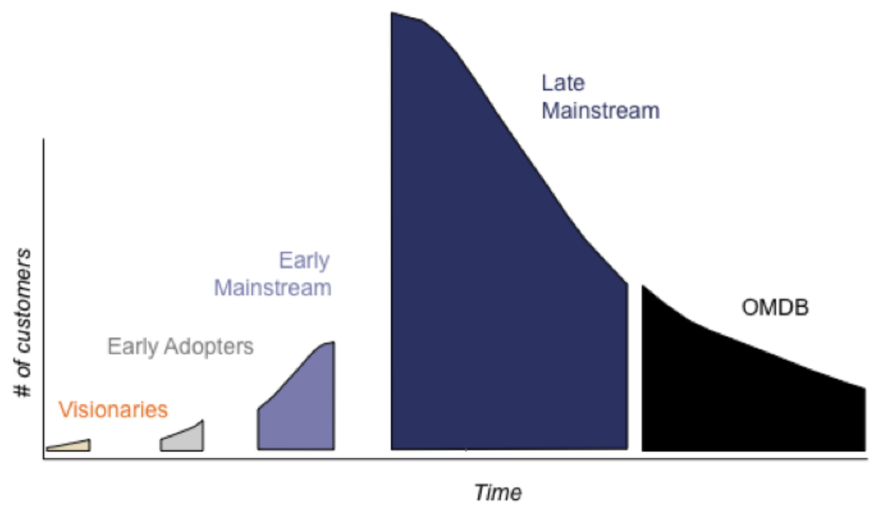

Figure 16: The customer adoption curve as it might be drawn for regulated utilities, which are highly risk averse.

Investing Beyond the Horizon

With evolutionary forces and special diligence in mind, we can now discuss likely investment themes. After decades of slow growth and investor neglect, the cleantech and smart grid sectors are gaining more attention, as these estimates from an industry analyst will reinforce:[10]

- At least 300 venture capital funds have entered the cleantech space in the past three years

- Of the venture money invested in the first half of 2008, more than 50% went to the smart grid space (including demand response)
- Of the 28 IPOs from June, 2007 to June, 2008, 10 were in the cleantech or smart grid space
- There are now at least 10 cleantech index funds
- Every major investment bank now has a cleantech practice
- An estimated $38 billion in various funds is now targeting cleantech – not counting the investment money available from private equity firms, utilities and regional angel groups

A 2008 report from consulting firm Booz Allen Hamilton pegged the worldwide cost of modernizing urban water, transportation and electricity systems at $41 trillion over the next 25 years. The Organization of Economic Cooperation and Development (OECD) estimate the world will need more than $1.8 trillion per year over the next two decades to upgrade infrastructure. In both cases, grid modernization is a major component.

Clearly, big dollars are at stake, with many smart firms competing to find the best places to invest. A combination of necessity and greed will force the electric power sector beyond its comfort zone and into a brave new world. We call this the "beyond" scenario, where pioneers will break through the barriers of current thinking. More specifically, they will go:

- Beyond traditional generation
- Beyond traditional transmission & distribution
- Beyond traditional business models

Beyond Traditional Generation

The bulk of this report focuses on the grid, the sector that will see the greatest impacts from the move to electronomics. But the generation sector will see many changes as well, changes that will ripple through to the grid. Some of the changes on the generation side will act as forcing functions, compelling utilities to upgrade and improve their grids.

Externals Become Internals

Economists define externalities as "*consequences of production ignored in pricing:* a factor such as environmental damage that results from the way something is produced but is not taken into account in establishing the market price." After a long free ride, the electric power sector will be under increasing pressure to factor externalities into its prices. In rough order of the magnitude of their likely financial impacts, those externalities include:

- Greenhouse gas emissions (primarily CO2)
- Non-GHG pollutants from coal and diesel generation such as mercury and ozone-depleting gases
- Transmission congestion (by regulating or pricing it more precisely to the people causing the congestion rather than forcing large groups to share the burden)

- Reliability and security (by imposing expensive fines on utilities that do not meet standards)
- Environmental and safety hazards (especially nuclear fuel)

It seems clear that the U.S. will adopt carbon standards within the next few years, but there is no way to know yet how deeply those standards will impact electric power. On the generation side, we expect coal and nuclear power to be disadvantaged versus renewables. On the grid side, we expect transmission costs to be allocated among all of the parties that benefit, not just to the region where the line is located.

Implications. Although it is too early to say with precision how these changes will affect business, it is obvious that investors must factor in future externalities charges as they make their choices.

Demand Becomes Supply

We've already documented the many forces pointing towards higher electricity prices. This pressure on prices is one reason so many people are looking to demand response as a partial solution. For the first century of its existence, the electric power industry had only one response when more power was needed – it increased supply by building new plants and new lines.

Now utilities are asked to consider reducing demand as an alternative. In this fashion, demand will become the "fifth fuel" after coal, natural gas, nuclear and renewables.

Demand-side reductions come in many flavors. The term *conservation* embraces programs that encourage consumers to save power by doing less. The term *efficiency* refers to new techniques for doing the same things but using less power (as with energy efficient compact fluorescents). And terms such as *demand response* and *demand-side management* refer to reducing energy use briefly in response to peak periods (or shifting it to off-peak hours).

Done properly, demand-side approaches have many benefits. They can do away with the need for standby plants and delay construction of baseload plants (and the grid expansion to support them). They can bring down costs by "shaving the peak," when the cost of delivering electricity can soar to 10 times the normal cost. And they can prevent expensive outages by providing a much-needed buffer when the grid is under stress.

Implications. The business opportunity comes from new technologies that allow companies to 1) aggregate many small reductions into a large total and 2) dispatch that aggregated reduction in real time, just the way an operator can turn on a peaking plant to meet a sudden upswing. In this fashion, companies such as Comverge and EnerNOC have made a business by aggregating so-called "nega-watts" that they can sell to utilities as if it were power from a generating station. (Or by operating this capability in behalf of utilities or large commercial/industrial customers.)

A number of startups have sprung up to cash in on the new technologies, the new support from regulators and the new interest by utilities. Comverge and EnerNOC have gone public. As of June 2008, both firms were projecting revenues to at least double every quarter (though profitability remains more elusive).

It is becoming apparent that success will be more than a matter of technology prowess. The winners will have to work with regulators and policymakers to ensure a regulatory climate that allows them to profit from the savings they can produce. What's more, winning firms will have to become very adept at marketing to consumers, who can be deeply skeptical of programs that allow the power company to control their air conditioners or their thermostats.

It may be too late for firms – whether larger or small – to build something from scratch for the burgeoning demand response sector. Instead, they may need to buy their way into the market. In the conservative utility space, size still matters. Utilities are reluctant to partner with new companies who could disappear in a year or two. These market realities point to a likely consolidation in the demand response space, moving from today's collection of regional providers to a handful of national players.

Storage Becomes Real

After decades as a theoretical possibility, grid-scale electricity storage will finally become a valid and valued part of the infrastructure. Part of the reason comes from the gradual improvement in technologies such as flow batteries, pumped storage, supercapacitors and flywheels. Part of the reason is the increase in renewables, which need a way to store the electricity they produce in off-peak hours. And which need help to supply the reactive power that helps balance the grid as renewables dip and surge.

The "traditional" grid has little or no electricity storage. Demand must be forecast and generation brought on and off line to match. This requires extra generation capacity in the form of spinning reserves and standby plants.

Cost-effective, high-performance energy storage has been the missing link for renewable energy. Now energy storage technologies are rapidly being commercialized to enable the widespread integration of intermittent renewable sources. In addition, there is widespread enthusiasm for a concept known as *vehicle to grid* (V2G). Tens of thousands of small batteries in electric vehicles would be plugged into outlets that would allow them to store and feed power back to the grid when needed.

Implications. We think there is a large and overlooked opportunity to produce reliable storage for a) the growing number of wind farms, and b) for "weak spots" in the grid that need to be propped up. We think it is harder to predict the trajectory of V2G.

It's not hard to understand the enthusiasm for the V2G concept. In theory, you pay for an expensive asset (batteries) just once but use it twice, once to power cars and again to store energy for the grid.

In reality, V2G is still in the honeymoon phase and the hurdles are just now coming into focus. For one thing, a battery suited to shallow automotive discharge cycles is very different from a battery optimized to withstand deep discharges every day to feed the grid. For another, it is still unclear how it will work. It's not even known yet whether homes and offices will need to be rewired with new "smart plugs," something that could add billions to the V2G price tag.

Most disturbing of all is the lack of a clear business model. Will utilities buy the batteries and lease them back to car owners? Will they give car buyers a rebate if they sign up to participate? Will they pay them for the power they give back? How will they monitor compliance? How will they record who gave up how much power and where they were plugged in at the time?

We believe early success will come to V2G companies that focus on high-value private opportunities such as urban delivery fleets. Firms that expect an immediate outpouring of large utility purchases may have years or even decades to wait.

Beyond Traditional Transmission & Distribution

The grid opportunities described below will benefit from an enormous backlog of deferred maintenance. The electric power industry virtually ignored its aging infrastructure for nearly 30 years. But the trends described earlier have caught up to utilities and transmission operators, giving them no choice but to repair and upgrade. Many are choosing to buy new-fashioned "smart" equipment rather than older electromechanical gear.

The spree has already started. From 2000 to 2005, spending on transmission projects rose by 60% from the previous five years, and is projected to continue to rise for the next 10 years at least.

Dumb to Smart

As outlined in Section 2, the electric power infrastructure is gaining intelligence and two-way communications. This transformation extends from generation facilities through the grid and all the way inside the customer premises.

We will not reprise our descriptions from Section 2, but we will remind readers that smart meters represent just one of the emerging opportunities (and one that may be due for upheaval). Smart devices will penetrate to all parts of the grid. Lesser known, less "sexy" sectors may have more potential for value creation. In early 2008, research firm Newton-Evans polled U.S. utilities about their smart grid plans and which areas were getting the most attention. Advanced metering infrastructure was cited by 51% of the utilities, the highest of any category. Distribution automation was mentioned by 41%, while energy management systems and SCADA were cited by 28%. All three areas are hot areas for investment, yet only advanced metering infrastructure is getting concentrated attention from a wide range of vendors.

Implications. Opportunities resulting from this trend include a long list of smart devices. Equally important will be the software that manages them all. The buyers of smart meters are now waking up to the need for advanced metering infrastructure (AMI), the term the electric power industry uses for the software that collects and manages the data from the meters.

Investors should be wary of old-line companies that "don't get it" and over-rely on customer lock in via proprietary standards or on electromechanical solutions. Likewise, they should be cautious about the increasingly crowded metering space. They may want to look instead at the market for software to manage the information from the smart devices that are proliferating throughout distribution systems, from transformer monitors to substation devices to line monitors and much more.

Backward to Forward

Until recently, utilities could only steer by "looking in the rear-view mirror." If they were lucky, they had software that told them the state of the grid 10 to 20 minutes previously. Most did not have even that level of situational awareness. Today the industry is on the cusp of advanced control systems that can look forward – that can model and simulate the grid, showing what is happening in real time and accurately predict what will come next.

The growing importance of command and control has been overlooked by utilities and vendors alike. Grid visualization is used for many purposes, including real-time load monitoring and planning for load growth. Although many different visualization tools exist, they share some general shortcomings:

- Lack of integration of distribution and transmission
- Lack of integration of different information from different sources
- Inability to accurately represent wide area behavior
- Inability to accurately represent appliance-level behavior
- Computation slower than real time
- One-size-fits-all views that can't be customized for different users, such as system planners, system operators, policymakers, or utility customers

The limitations of the current generation are even more challenging given the explosion in the amount of data to process. Consider, for instance, these recent developments, all of which increase the amount of data and the need to understand and act on it:

- Smart meters can deliver hundreds of times as much data as former once-a-month meter reads
- Demand-side management requires advanced system controls and monitoring
- Renewables require high degree of weather and load predictability
- Customer-based demand response requires big amounts of information
- Transferring larger amounts of power across the grid requires a higher level of system awareness
- The threat of terrorism and natural disasters requires securing and monitoring critical infrastructure
- Market liberalization require communication and coordination between a growing number of generators, power marketers and transmission operators

VERDE, a project being developed at Oak Ridge National Laboratory for the Department of Energy, provides a sneak preview of the future of this category. It can integrate real-time sensor data, weather information and grid modeling with geographical information. It has the potential to explore the grid at the national level and then, within seconds, explore specific details at the street level. It can provide fast information about blackouts and power quality as well as insights into system operation for utilities. The entire platform is built on top of Google Earth, and can take advantage of content generated by Google Earth's user community.

Implications. One obvious result of this trend will be to increase sales for makers of visualization software. But watch as well for opportunities for areas that touch or support this function. One example is the provision of large-screen displays and the software to control them. Another is the systems integration skills to take information from many different sources and marry it into a single control system.

Central to Distributed to Micro

The world is transitioning gradually from massive centralized power plants towards medium-scale distributed generation and, ultimately, to small-scale "just-in-place" power production. To be sure, centralized plants will have an important role for many decades. But much of the overall growth in supply will come from distributed generation.

Researcher Amory Lovins claims "micropower" produced one sixth of the world's total electricity and one third of the new electricity added in 2005. For the first time, micropower produced more electricity worldwide than nuclear power. The map below shows how Denmark made the transition from centralized to distributed power in roughly 20 years. **(Figure 17.)**

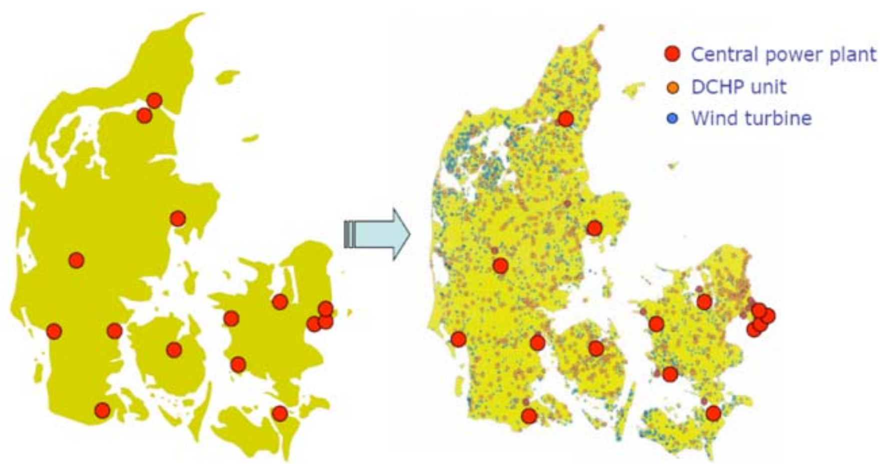

Figure 17: In the 1980s, Denmark relied almost exclusively on central power plants (left). By the 2000s (right), it had transitioned to a system with extensive distributed power (mostly combined heat and power and wind turbines).

Much has been written about the world's gradual transition to distributed energy. Far fewer people have noticed the potential for the trend to continue down to the microgrid level.

A microgrid ties one or more small generation sources together on their own feeder line. Then it links that feeder to the grid at a single point. In the event of a disturbance, the microgrid seamlessly separates and isolates itself from the utility grid, while maintaining power to its local customers. When the utility grid returns to normal, the microgrid automatically resynchronizes and reconnects itself.

Three macro trends are converging to make microgrids appealing:

1. Security. More and more countries, states, provinces, cities and military bases are facing up to the dangers of terrorism and natural disasters. They are searching for ways to insulate themselves against failures of the larger grid.

2. Self-reliance. As more and more industries go digital, they are bumping into the requirement for high-quality, interruption-free power. As the CTO of tech giant Oracle once put it: "We don't worry about the cost of power. We worry about the cost of not having power." Interruptions can cost thousands of dollars per minute for commercial, industrial and financial users. As these companies consider their options for backup power and onsite generation, they discover microgrids as an interesting new approach. For instance, Wal-Mart has created microgrids for two facilities, one in McKinney, TX, and one in Aurora, CO. They draw their energy first from onsite resources, then from the grid as a secondary service. (They apply dozens of energy efficiency techniques as well.)

3. Standards. Until recently, each interconnection to the larger grid was a custom job. As a result, costs were exorbitant. Now standards are emerging. The National Renewable Energy Laboratory is leading the charge to create national interconnection standards. And a coalition of national and university labs is developing plug-and-play microgrid specifications in partnership with utility giant American Electric Power. As these standards are proven and penetrate the market, they will bring down costs and installation time.

A new financing tool may also accelerate the growth of microgrids and distributed generation. Under a Connecticut law passed in June 2007, municipalities may now form "energy improvement districts" (EIDs) with the authority to issue state tax-exempt bonds. The name is a play on the familiar "local improvement districts" long used by property owners to band together to pay for things such as street paving, sewers, or street lighting. In the case of EIDs, the bonds pay for small-scale, locally sited, self-sufficient microgrids.[11]

Microgrids are also a way to start small without waiting for the funds to remake the entire grid top to bottom. From the 2007 book *Brave New War* by John Robb: "[The scale of the Smart Grid] means that the changes contemplated are too expensive and too wrenching to accomplish on a large scale (akin to boiling the ocean). The only way to implement these new technologies and methods is to find a way to do it organically. The microgrid enables this by creating a local network (electricity plus data services) that can become a platform for the organic growth of a diverse and innovative ecosystem of solutions and providers."

Implications. The microgrid trend is nearing a tipping point that may catch some investors by surprise. Microgrids are already an area of intense interest for progressive North American utilities. They will become top of mind for the mainstream in 2009 and 2010, as several important research and pilot programs reach culmination. Europe may well outpace the U.S. in adoption, as will island nations, states and provinces, which have even greater incentives to tap into multiple sources of generation.

Navigant consultant Stan Blazewicz is the co-author of a 2008 study titled "How 'Microgrids' Are Poised to Alter the Power Delivery Landscape." For the next few years, says Blazewicz, microgrids will be facilitators of solar PV and large combined heat & power, where the additional cost and complexity of a microgrid can be cost-justified. As the technology matures, it will become simpler and cheaper and will be used to integrate many distributed resources, including energy storage and demand response.

At that point, the whole microgrid can be made to look like a single, dispatchable entity to the utility, even though its "power" is made up of a combination of demand reduction plus storage plus different kinds of generation.

Stovepiped to Unified

At the same time it gains the ability to look forward, command & control will also gradually unify. Systems that today require separate command & control systems running on separate monitors will be combined into a single system. This unification may occur in a single, centralized control center. Or the control functions may be distributed, so that a utility in effect has many small control centers scattered about.

At the transmission level, operators will be able to scan wide areas and view information from multiple control systems. At the distribution level, operators will be able to work with virtually any application from virtually any console. At the microgrid level, municipal and private utilities may move toward a unified model – supplying and control electricity, water, waste management, security and emergency response through a single entity.

Roads to Freeways

Earlier, we described the "Central to Distributed to Micro" tendency, which predicts smaller plants much closer to customers, thereby decreasing the need for long-distance transmission. Despite this trend, other forces are at work that will mandate new high-voltage transmission. They include:

- Moving power from bulk renewables (wind farms, solar thermal, ocean, wave, hydro) from where it is made to where it is needed. For instance, several large transmission projects are underway to ship wind power from Western states where it is made to California where it will be consumed
- Moving power from lower-cost regions (such as the South and Midwest) to higher-cost regions (such as the Northeast)
- Creating redundant pathways to reduce the grid's vulnerability to disaster or attack
- Upgrading existing lines to carry more power (thereby reducing the need to carve out new transmission corridors through people's backyards)
- Building out the grids of emerging nations

Many experts continue to recommend an "electricity superhighway" for the United States and Canada, one that would criss-cross North America delivering bulk power. Whether or not the U.S. embarks on next-generation transmission, other regions are already at work. The "Gulf Grid" project is underway, linking major nations of the Middle East. Portions of the Chinese grid are extremely advanced. And Europe is discussing major projects to link hydro from Scandinavia all the way to wind in Spain.

As you have read, the Brattle Group predicts the U.S. grid will need close to $1 trillion in new investment between 2008 and 2030. Other sources forecast even higher numbers, especially for the world as a whole. According to the International Energy Agency (IEA), a cumulative $13 trillion is needed worldwide during that period, more than half of that for the grid and related equipment (as opposed to new or refurbished power plants).

Implications. The early beneficiaries of the roads to freeways trend are the large construction and engineering firms, whose dance cards are now filled for several years ahead. Going forward, the build out will also increase demand for grid monitoring tools such as phasor measurement units, for advanced power flow controls and for wide area management systems. As the grid gains the capability to ship more power, demand will also increase for the market management software that allows companies to trade and track power shipments.

Data to Intelligence

The power of Wal-Mart's electronic cash registers is not in the mountains of individual data points. It is in the business intelligence – the trends that can be mined from that data. Those trend lines allow Wal-Mart to react to a new development before its competitors even know it has taken place.

Likewise, the power of intelligent grid devices (meters, monitors, sensors) is in the deductions that can be pulled from the data. The electric power industry is far behind retailing, manufacturing, telecommunications and business computing in creating valuable information from its data. Enormous opportunities exist for companies that can collect, normalize, analyze, present and share data.

Implications. To some extent, we can predict the effects of this trend by looking to other industries that went before. The utility sector will undergo a similar evolution. For instance, we will first see "point solutions," standalone applications that solve a single point of pain such as metering applications. Next we will see attempts to link the point solutions to legacy apps from the back office, such as metering to billing. Next, applications will pull data from multiple sources. For instance, outage management may pull from metering, asset management, and GIS. Similarly, we'll see solutions that analyze data from multiple sources to look forward – predictive maintenance for expensive assets, load forecasting, network design and network optimization.

The culmination will be "middleware" that can integrate multiple applications from multiple vendors. We expect most utilities of any size to end up with one platform in the back office and another platform for the control room and field.

This and other technology trends will make a new "platform" business model possible for vendors, as we will discuss in the next section.

Meter to Dashboard

As utilities go from data to intelligence, they will begin to present that intelligence to customers to allow them to make better energy choices.

Imagine a family of five, two parents and three teenagers, all with cell phones. Now imagine that they get a monthly phone bill that has only a single total charge. One month it may be $250. The next month $700. There is no explanation. No way to know if the excess charges come from a teenager who talked too long or a parent who racked up roaming charges on an overseas business trip.

Today's electric power bills are just as opaque. Consumers receive a single bill with no way to know which devices are responsible or whether they could save money by "load-shifting" (by moving use to off-peak times).

That is about to change. In Europe, Italy switched all of its electricity customers to smart meters several years ago. In the U.S., utilities have announced plans to deploy more than 40 million smart meters over the next three years as of spring 2008, according to FERC. In California alone, the public utilities commission has approved deployments worth roughly $3.5 billion.

Despite these rosy predictions, it is unclear whether meters will continue to accrue more intelligence. Some utilities are starting to push back. They do not want to be responsible for maintaining a small computer shoehorned inside a meter that hangs on an outside wall. They would prefer to see so-called "home gateways" or "consumer portals." Such devices would gather data from meters, but they would also handle all other aspects of the smart home of the future.

We expect to see a gradual transition to a "dashboard" inside the customer premises, starting with industrial/commercial customers and eventually moving to residential customers. That dashboard will allow electricity customers to see the where and when of all their power consumption. What's more, they will be able to control the parameters. For instance, some customers might choose a lower electricity rate in return for allowing the power company to cycle the air conditioner off briefly during peak summer demand.

That dashboard is also likely to control lighting, HVAC, industrial processes, and audio-visual (in the consumer space).

Who will supply and maintain that dashboard? Many companies want to own the centerpiece of the Home of the Future. Possibilities include cable companies (Comcast), personal computer makers (Microsoft), Internet equipment makers (Cisco) or audio/video manufacturers (Sony). The winner will be decided by a variety of factors. They include who has the best channel to customers and who has "permission" to play that role

Implications. The obvious expectation is rapid growth in shipments of smart meters, as reflected in the rosy reports from meter makers. And there is still plenty of headroom, at least in theory. Seattle's R.W. Beck estimates that the U.S. has 130 million electric, gas and water meters. Only one fifth are "smart" and only about one twentieth are being used to their full potential.

These theoretical numbers, however, may not represent the best investment opportunities. Many investors have already moved into the meter space. It seems likely margins will decline as more suppliers entry the fray (including low-cost Chinese manufacturers).

The move from meters to dashboards creates a need for the software to connect all the pieces. And for the systems inside the utilities to collect, verify, and normalize the flood of data, and then to ship it off to the many applications (existing and yet to come) that will need to make use of the information.

One long-term possibility is "micro-metering" – the ability to measure the electricity consumption of each and every device. In the short term, such capabilities are already appearing in industrial settings, server farms and other places where there is great value from knowing which equipment is using the most power. We expect the trend to migrate downward slowly, ultimately appearing as a chip-level feature that is built into appliances. (Microsoft and other software companies are already prototyping standard ways for devices to communicate such information.)

Beyond Traditional Business Models

Utilities, vendors, regulators and policymakers should be preparing for an upheaval in traditional business structures. In some cases, the trends documented above allow new business options. In other cases, they virtually mandate new approaches, since the old ways simply won't work much longer.

That the vendors will change is taken as a given by most observers. That the utilities will change is still greeted with skepticism by some. Yet this period of upheaval is arriving just as a big population bulge is set to retire at most utilities. (Some utilities could lose 40% of their workforce to retirement in the next five years). The baby boomer retirement phenomenon will usher in new, younger managers that may be more open to change.

Quantity to Efficiency

The regulatory compact first established in the 1930s in the United States was designed to provide predictable prices for the captive customers of a monopoly. Many U.S. utilities are still regulated under that outdated system. Infrastructure investments are recovered over decades based on assumptions about consumption and growth. Often the formula is simply *price* times *quantity*. But that formula is at odds with the modern need to conserve power, since the utility is more profitable if customers use more electricity. Wasteful customers can lead to better earnings.

As rates climb and populations grow, it will become painfully evident that energy efficiency must be a priority everywhere. State and national regulators will gradually "decouple" the price-times-quantity equation. They will find other ways to reward utilities besides paying them more when they sell more electricity.

Implications. One benefactor will be companies that can offer energy efficiency services to utilities or to their big customers. Comverge, for instance, started out selling demand-response "nega-watts" to utilities. Today it also has a division that helps commercial/industrial customers become more energy efficient. Likewise Advantage IQ (originally a spin-out from Pacific NW utility Avista), manages energy bills for corporations with widespread operations.

Commodities to Specialties

Today, most electricity customers treat electric power as a commodity. Usually, they can choose only one "flavor" of electricity at one price. There is little perception that one type of power is any better than another.

In the future, customers will be able to choose from a wide variety of power plans tailored to their needs and budgets. We may see distinctions by source (coal-based vs. green power), by purpose (baseload or just in case), by quality (guaranteed uptime), by rewards for behavior (lower rates for those who allow demand response), and more.

The nation's power bill is more than twice the size of the nation's phone bill. Most electricity customers can "have any color they want as long as it's black," whereas phone customers can choose from a variety of methods (landline, VoIP, cellular), features and payment plans. With so much money at stake, electricity customers will demand the same kind of choice and selection. And they will slowly get it, as technology improves and as regulators awaken to the consumer benefits of competition.

Implications. As the Stanford Financial Group explained in its April 2008 *New Electric Trends,* this transition to "gourmet electricity" may not sound revolutionary, but it represents a significant change in the investment bargain. We are moving "away from the century-old approach most utilities have been living with – produce power as it is needed and send it across power lines to consumers who are insensitive to the incremental costs – to one that provides for more personalized choices."

Owning All to Owning Some

As described in the discussion of the "Vertical to Horizontal" evolutionary force, utilities are gradually moving away from the top-to-bottom, we-own-everything business model. Combined with the growing cost pressures (rising fuel prices, carbon and other externalities priced in), this change will encourage utilities to explore other ownership structures. Regulators are likely to become more accepting of alternative approaches as well, since they will be under pressure to find ways to finance needed improvements that do not involve large, upfront capital expenditures.

Implications. Vendors may be able to gain market share not just with technical innovations, but with financial innovations as well. These may take forms such as sale/leaseback; design, build, operate; outsource; joint venture; or cost-sharing consortia, to name a few. Already we are seeing companies that sell their expertise in financial and regulatory structures just the way they sell their technical expertise.

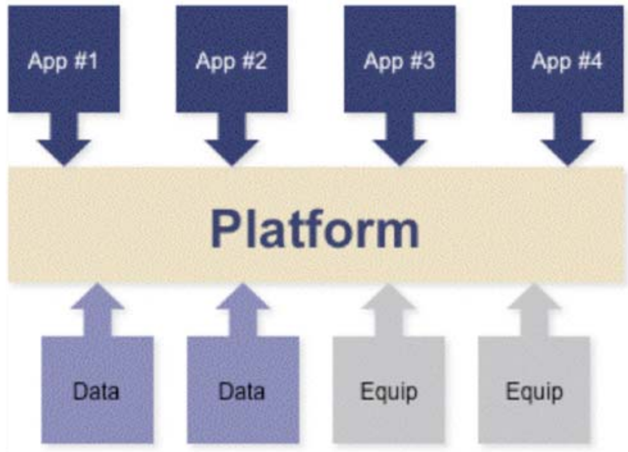

Figure 18: A simplified conceptual drawing of a platform, which acts as an intermediary and "translator."

Point Solution to Platform

Today, most vendors compete to provide a solution for a single point of pain. Over the next five years, we expect intense competition to become the "integrating platform" that pulls together and manages those individual applications. **(Figure 18.)**

The platform concept is easy to understand in the context of computing, where Microsoft Windows acts as a platform. Windows talk to all sorts of equipment (computers, monitors, printers), accepts all sorts of data, and runs all sorts of programs, handling the "translation" between them.

In enterprise computing, companies such as SAP, Oracle and IBM that have successfully created platforms. In the Internet sector, companies such as Google and Facebook are competing to become the favored platform for social computing.

Implications. The next five years will be chaotic as multiple players via to become the de facto standard. Startups such as GridPoint are already talking the platform talk, from a technology integration direction. Companies such as Comverge and EnerNOC have gotten good at demand response and could choose to integrate more than just demand response for customers.

We may also see platform plays from the back office vendors, who will reach out from their accounting and billing roots and talk directly to field applications. Some of the vendors now managing meter data will offer to centrally manage all data. And vendors of energy and distribution management software, such as Areva T&D, could easily play a central role, by building or buying extensions to their control room software.

We may even see platform attempts from adjacent sectors such as networking, such as Cisco, computing, such as Microsoft or IBM and command & control, such as defense and space contractors.

Disconnection to Aggregation

A world where everything is connected – down to the smallest device – creates the ability to aggregate small things into a whole that has more value. Demand response is an obvious example. During a grid event, turning off a single air conditioner will have little effect. Turning off 10,000 air conditioners, on the other hand, can make all the difference. Today's upstart demand response companies recognized this trend and developed software that lets them aggregate thousands of users into a block of predictable power reduction.

Thanks to rapidly advancing hardware and software, aggregation capabilities will continue to grow. "Granularity" will improve, allowing firms to control smaller and smaller devices.

Implications. Demand response will continue to grow in thanks in part to the increasing ease of pulling together many small loads and managing them with precision. We may also see increased aggregation on the supply side – bundling up lots of small wind and solar to present a block of green power, for instance. Iberdrola SA, the Spanish company has done this in Europe and is beginning to do it in the United States.

We may see "independent power aggregators" that can package up demand and supply and present the combination to utilities (making on-the-spot adjustments all day long to rejuggle the mix as needed).

Certainly we will see attempts at aggregation on the buy side. As retail competition for electricity gradually becomes the norm, intermediaries will aggregate the power needs of many users to gain a "bulk rate." Chain operations may package up multiple locations into a single buy.

Conclusion

Although still overlooked and undervalued by some, the Electricity Economy has now reached its tipping point. The world has no choice but to modernize its electric power infrastructure. This renewal will require tens of trillions of dollars in new investment, sending waves through the world economy for the next several decades.

To be sure, this new landscape requires careful study. Progress will be piecemeal, scattered and subject to regulatory delays. Some of the experiments will fail. And some of the best opportunities maybe counter-intuitive or "boring" compared with the categories that capture the headlines.

If they act with care, however, astute investors and entrepreneurs have the chance to stake a claim in a vast new territory. We hope the investment themes outlined in this white paper will help to navigate this emerging sector.

Endnotes

[1] Table 1: Examples of Electricity Growth Trends

a) U.S. Census Bureau, "Total Midyear Population for the World: 1950-2050", http://www.census.gov/ipc/www/idb/worldpop.html

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c) CIA World Factbook, December 2003, "Televisions by country", http://www.nationmaster.com/red/graph/med_tel-media-televisions&b_printable=1

d) CIA World Factbook, December 2003, "Televisions (per capita) by country, http://www.nationmaster.com/graph/med_tel_percap-media-televisions-per-capita

e) DOE Energy Information Administration, "Table 8. Electricity Supply, Disposition, Prices, and Emissions", http://www.eia.doe.gov/oiaf/aeo/excel/aeotab_8.xls Note: Calculated compounded increase 2006 - 2030 = 1.02277/yr. interpolated +/-50 for 1950 and 2050

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g) Forrester Research, "Sizing The Emerging-Nation PC Market," Dec. 2004. Note: 1950 and 2050 entries are proportional to World Population. Number of televisions per thousand people divided by 3.7 people per household (global average).

h) "Computers", Collier's Encyclopedia Vol. 7, 1992: 114, 129. Note: Almost 54 million personal computers were installed with a total value of 92 billion (In 1981, by way of comparison there were fewer than 2 million personal computers in use in the United States.) http://hypertextbook.com/facts/2004/DianeEnnefils.shtml

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[2] U.S. Council on Competitiveness, 2007

[3] American Power Conversion, 2002

[4] Pacific Northwest National Laboratory, 2006

[5] The Brattle Group, 2008

[6] Edison Electric Institute, 2008

[7] Edison Electric Institute, 2008

[8] The Brattle Group, 2008

[9] A Systems View of the Modern Grid, NETL Modern Grid Initiative, Jan. 2007

[10] Avior Partners, June 2008, public presentation

[11] *SmartGridNews.com,* Nov 13, 2007