THE HUBER MILLS digital power report

Special Report

The Powerchip Paradigm I

Digital Power

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First published September 1999; updated December 2000

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Powering the Telecosm
SPECIAL REPORT
Published by Gilder Publishing, LLC

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Hundreds of billions of dollars per year are going to be invested in new technologies to move, condition, store, and distribute electrons for the digital economy.

We are entering the century of the electron.

Not the information century? The communications age? The bit era?

Well, bits are electrons: small buckets of them stored in silicon capacitors, or propelled through metal wire, or (transformed into photons) oscillating through glass or air. Bits are, at bottom, packets of energy that have to be sifted, herded, and propelled across planes of silicon and through tunnels of copper, coax, and glass. This takes electricity: flows of electrons.

Not much electricity—not for just one bit. But the number of bits in motion is growing at big-bang speeds. One result is that while electricity accounted for 25% of our energy consumption 25 years ago, it accounts for 37% today. It will account for more than half U.S. energy use by early on in this century. Most of those additional electrons will flow into information devices. But far more important than the sheer increase in the volume of electrons demanded by information technology is the type of electricity the information economy requires. Bits demand unusually clean, stable, reliable electrons. Electrons for bits cannot be reliably provided by the same old technologies on the same old power grid that powers our light bulbs, electric motors, or air conditioners, or at the same old price.

To accommodate this great energy shift, much of the sprawling infrastructure of the U.S. power grid will have to be rebuilt. Unlikely though it may seem, your century-old power company—stolid and plodding, funded by ratepayer bonds and entangled in sclerotic commissions—is now hitched to the dot-coms. It may prosper with them, or it may end up as road kill, but either way its destiny is now linked to theirs. Hundreds of billions of dollars per year are going to be invested in new technologies to move, condition, store, and distribute electrons. The companies that will do this range from the familiar to the unknown: Caterpillar, GE, ABB, American Superconductor, Siemens, SynQor FuelCell Energy, Emerson Electric, International Rectifier, IXYS, Power One, Advanced Power, Silicon Power, Proton Energy, Active Power, Capstone, Beacon Power, and dozens—or if we include component makers and utilities themselves, hundreds—more.

The New "Chip"

Compare two silicon chips, side by side. One—call it "SmartChip"—contains 100 million gates. Each gate operates at one microwatt of power; the entire chip consumes 100 watts. The other—call it "PowerChip"—contains just one, mammoth gate. But it is big enough to switch a megawatt.

SmartChip is, of course, the building block of the Internet Economy, spanning companies like Cisco, Intel, AOL, and Microsoft; Sun and IBM; E-trade, Yahoo!, and Cnet; Amazon, eToys, and WSJ.com. SmartChip has taken apart and put back together mainframes and micros, switches and routers, banks and brokerage houses, bookstores and newspapers, radio stations and televisions.

And PowerChip? It is now poised to take apart and put back together the trillion-dollar U.S. network of central power stations and transmission distribution lines, and the $500 billion-a-year kilowatt-hour economy.

PowerChip is in fact the older sibling in the solid state family. Selenium diodes, used as switches in power supplies and amplifiers, entered commercial production in the 1950s. International Rectifier—a founding company of solid-state technology—went public in 1958. As IR's founder observes, "selenium diodes begot germanium diodes, which in turn begot silicon diodes, which then resulted in commercial transistors and thyristors, and then begot ICs which begot memory and microprocessors."

Though PowerChip was the first born, SmartChip grew up a lot faster, propelled up the steep curve of Moore's Law by technological advances that etch ever-finer gates, pushing circuits ever closer together, ramping up processing speeds even while pushing down power requirements. As our colleague George Gilder summarizes in the law of the Microcosm, "the less the space, the more the room."

PowerChip lives in a different world altogether. For PowerChip the goal is not to make ever smaller gates requiring less and less power, but ever bigger ones that can switch more and more power, faster and faster. Denied all the rich paradoxes of miniaturization that drove the silicon learning curve for SmartChip, PowerChip technology has proved even more challenging. PowerChip does exactly what a transistor does, uses a smaller current to switch a larger one. But in this case, a much larger one. That turns out to be a very big difference indeed.

The millions of tiny gates in a microprocessor perform their switching at micro-watt power levels. A PowerChip switching "gate," which can switch an entire office building from the utility grid to a backup power source, has to handle kilowatts, or even megawatts. Power-wise, that's about the difference between a hang glider and the space shuttle. At that power density the electrons literally push the atoms of the conductor around and create their own circuits. If you let them.

With a PowerChip, speed is everything. The slower your PowerChip switches, the more heat gets generated while it's flipping from open to shut. Ten milliseconds is no big deal when you're switching 10 watts. In a 10 MW switch, however, a 10 ms switching time means your chip is toast. Today's high-power thyristors meet 1,000 V/microsecond and 400 Amps/microsecond standards. That's fine for switching 6 MW, but still chump change compared to the power levels in the backbone of the electric power grid.

To handle higher power levels, you pile 8 kV/8 MW silicon thyristors into a very tall stack—up to 50 feet high, with lots of extra space for heat sink and cooling. Now, you're set to switch 80 MW—if you can fire all those thyristors exactly simultaneously. But if one of those stacked thyristors goes off even microseconds early, it takes all the power by itself, and explodes.

The pre-history of the PowerChip spanned the two decades between 1975 and 1995. During that period, power ratings of individual PowerChips barely doubled. Nevertheless over the past ten years, the market has grown at a compound annual rate of better than 15%, until by 1997 power conversion semiconductors comprised an $8 billion market.

In the late 1990s, advances in PowerChip technology began to accelerate very rapidly. Today, PowerChip technology is crouched at the sweet spot of its learning curve, at about the same point Intel occupied in its business in 1979: poised for three-digit annual growth, with production volumes doubling or redoubling inside a year, yielding Moore's-Law-like accelerations in switching capacity per dollar. As that happens, PowerChips will seize control of the MWs, as inevitably as SmartChips seized control of Mips.

Today only about 12% of the world's electricity is switched by PowerChip. But 100% penetration is inevitable, as PowerChip accelerates up the learning curve. And the most crucial, and profitable, market will be satisfying the power requirements of the SmartChip. The PowerChip is the one technology that can satisfy the surging demand for something altogether new in the power business: "Ten Nines" of reliability.

The Tenth Nine

A remarkable number of bad things can happen to a power system woven out of tens of thousands of miles of lines: "car-tree interactions," and Mother Nature being just two. Solar electric storms induce huge currents in the grid's long wires. Such storms follow a predictable 11 year sunspot cycle. The last peak, which began at the end of 1989—back in pre-Cambrian Internet time—put six million people in the dark on Quebec Hydro's systems. The next peak starts within a year.

Worse yet, the network is as much a part of the problem as part of the solution. Every time a big motor starts up at a water plant, or an electric welder fires up, power spikes surge and ripple up the grid. A few years back a Stanford computer center found its power fatally polluted by an arc furnace over a hundred miles away. With only a couple of prototypical exceptions, all switching on the grid is still electromechanical. A spring helps speed-up the switching, which minimizes—but does not eliminate—arcing, and a concomitant burst of electrical noise. Such Rube Goldberg devices fire up and down the length of the grid, hundreds of times a day.

For all that, our trillion-dollar electric network is a remarkable achievement. Some 15,000 central power plants deliver over 3 trillion kWh per year, with (roughly) 99.9% reliability. That's "Three Nines"—or about 8 hours of outage a year for a typical consumer.

Before smart chips, that was good enough. The electricity system was built in response to three main waves of demand, each a function of a new invention: the light bulb, the electric motor, and the air conditioner. For each of these technologies 99.9% reliability was acceptable—considering the high cost of further improvement. It gets very expensive, very fast, to boost reliability much above that.

Hospitals, airports, and military bases have demanded better than Three Nines for years, and have deployed their stand-by generating systems accordingly. Phone companies deploy huge battery banks and gas-fired stand-by generators alongside their large central offices, to keep phone lines up even when the lights are out. But smart chips have changed the power world in two ways. As microprocessors and Web links penetrate deep into the economy, in to the facilities of even "ordinary" manufacturing and commerce, power quality and reliability become as important to "old economy" companies as they are to Bell Atlantic and Amazon. Residences are next, as smart chips come to permeate the home. The sheer magnitude of devices and users that depend on smart chips is unprecedented, and accelerating.

Smart chips, the devices that use them, and the networks that connect them, create a new standard far beyond Three Nines. Reliability demands start at Six Nines for the telecom and dot-com world—99.9999% up time. At the fifth Nine we're into minutes of down time a year, tolerable for a home-owner, unacceptable for any serious dot-com company. At Six Nines, we're talking 30 seconds outage a year.

But Six Nines is still orders of magnitude away from the reliability required to power smart chip industries and companies. At the seventh nine, several seconds a year, we're protecting against a spectrum of minor distortions on power lines; common occurrences that last less than a minute, but are still seen by smart chips as network crashing events. At the eighth nine—99.999999%—interruptions are measured in hundreds of milliseconds—a trivial flicker for a light bulb, but still enough to crash a smart chip. It's only around the ninth and tenth Nine that the power can really be labeled clean enough for smart chip purposes.

Here's the rub. Practically speaking the traditional power grid will never be able to provide much better than Three, perhaps Four Nines of quality. The grid, distributing power over vast distances, is necessarily too exposed to catastrophic events to ever satisfy the smart chip's real needs. Rebuilding it to do so would make it too expensive to support the economy power needed by the dominant 'dumb' appliances on the grid. To add Nines, we must turn to an array of systems, ranging from capacitors and inductors mounted on a motherboard or in a UPS (uninterruptible power supply) to fix problems of milliseconds duration; to batteries, flywheels, and super-conducting coils to compensate for outages of seconds to minutes; to diesel generators and turbines to supply back-up for hours or weeks. Every step requires a switch that can operate fast and cleanly enough to make the switching process invisible to the smart chips. That's the powerchip's job.

Building in reliability is expensive and it gets more expensive for every additional Nine. But smart chip companies have no choice. Clean power, information-quality power, is becoming a *sine qua non* of the information economy and thus one of the greatest business opportunities of our time.

Information-quality power is one of the greatest business opportunities of our time.

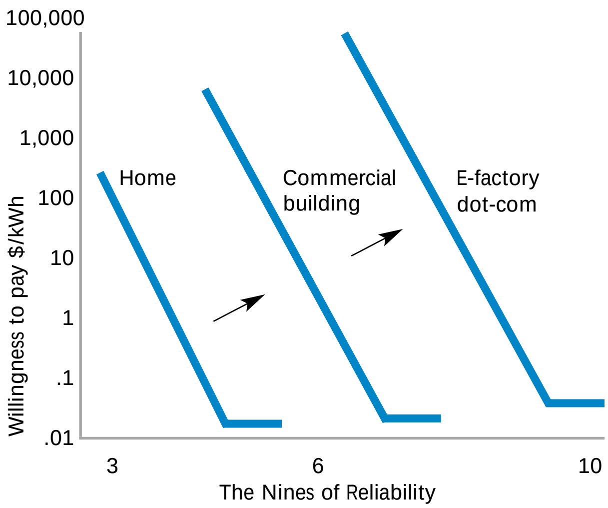
How much will people pay for the next Six Nines? Well, what does it cost a company like Schwab to go off-line for an hour? Or a day? What does it cost the cell phone company that loses a cell site in mid-town Manhattan? What does it cost the harried home-office worker, on a deadline to complete a report? That's how much the extra Nines are worth. Which is why information-quality power is already being sold at rates and in volumes that make clear this market will yield profits far surpassing anything dreamt of in the electric industry for decades.

True, the volume remains in the Three Nines market, the market for regular old grid power now increasingly traded coast to coast as a true commodity. But as we add Nines the cost, and the value, of the electrons rises rapidly. A single central power plant up 99% of the time delivers Two-Nines electricity wholesale into the grid at 2¢/kWh. A number of such plants woven into the grid allows utilities to deliver 99.9% reliability at about 10 ¢/kWh retail at your plug.

For every Nine after that, the costs soar. Three extra Nines can bring a 200 to 1000 fold price premium. But that's a premium that chip-centered businesses—which will soon mean all viable businesses—will readily pay. Information-based businesses have been doing so for some time. You have almost certainly done so yourself, though you probably didn't think of it that way. When you buy an American Power Conversion (**APCC**) UPS to keep your desktop PC isolated from ubiquitous line voltage sags, what you're really doing is paying $20/kWh; roughly 200 times retail. True, you buy only one kilowatt-hour per year at that price—spread out over 20 five second events each using 0.05 kWh. But with millions of customers, APC is a $1 billion-a-year power company. The challenge and the costs are modest at the desktop though. Costs and value rise exponentially with power.

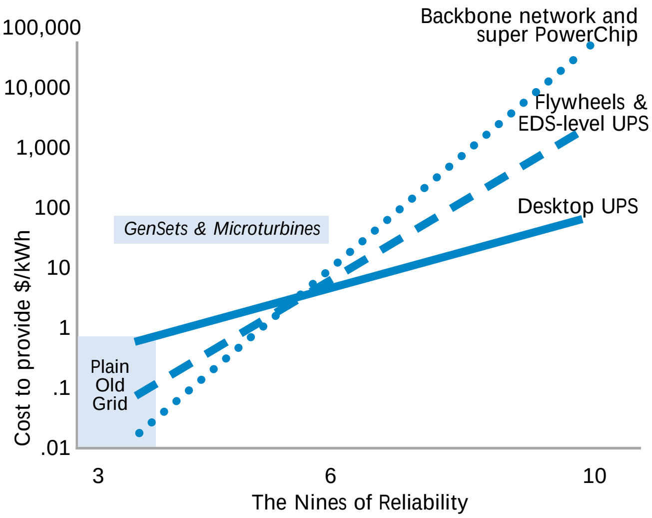
Companies at the core of the smart chip economy require very large quantities of High Nines power. At the semiconductor manufacturing plant level, or the

Demand Curve for Nines



All sectors are moving up an inexorable demand curve towards higher reliability (High Nines), and higher willingness to pay for that quality.

Supply Curve for Nines



The grid is the low cost supplier only for Low Nine power. Distributed generation and power electronics beat the grid for Higher Nine supply.

major dot-com level, the per kWh cost of more Nines hits the stratosphere.

If a voltage sag becomes a sustained outage, you kick into an on-site diesel generator, in effect a Five Nines device. The imputed electric cost can be as high as $5/kWh for a few hours of annual use.

But to make a seamless transition from the grid power to the diesel generator, a transition measured in milliseconds, requires batteries (sometimes flywheels) and powerchips. The resulting Six Nines reliability comes at a cost of perhaps $1,000/kWh.

At the high end, factory-power levels, powerchips combine with superconducting storage devices to supply the capability to pump megawatts into the power curve in fractions of a 60-cycle wave. The implicit cost of power delivered at these Nine and Ten Nines levels ranges beyond $100,000/kWh.

Clearly, there will always be a lot more Three Nines kWh sold than those at Six Nines and up. But with these price spreads, you don't have to sell a lot of High Nines kWhs. Caterpillar (**CAT**) in selling diesel generators is really selling Five Nines. APC is selling Six Nines. American Superconductor (**AMSC**) sells Seven Nines. Silicon Power sells Nine Nines. At each successive tier of Nines stands another multi-billion-dollar market.

In aggregate, the total market for kilowatt-hours above Three Nines is already 20% of the Three Nines market and growing at double-digit rates.

As smart chips continue to reorder the economy, the aggregate profits in premium power and powerchip companies will soon exceed those in the Three Nines market. This transition will turn the electric industry upside down.

One finds High Nine companies falling into three categories: Clean Power Systems; Ride-Through Systems; and Stand-Alone Local Generators.

Clean Power Systems

Powerchips clean up power by switching it fast, mediating between electrons coming off a primary power source and electrons temporarily stored in good-sized capacitors and inductors alongside the powerchip itself. It's impossible to store much total energy on a circuit board, but you don't need a lot to clean up blips and dips. What you do need is very fast, accurate, and intelligent electronics to mediate between the dirty source and the on-premises reserves. powerchips do the job.

On a motherboard the small amount of power needed for a few milliseconds can be handled by finger-sized capacitors. But at the megawatt local network level, even a few milliseconds entails the use of capacitors the size of a stack of oil drums, or American Superconductor's refrigerator-sized superconductors. At the network level, Siemens Westinghouse Power (**SMAWY**) has developed a power-electronic based "Dynamic Voltage Restorer" (DVR) that can fix high power voltage sags in real time for loads in the 2 to 26 MW range, enough to keep, e.g., a semiconductor fab humming.

Ride-Through Systems

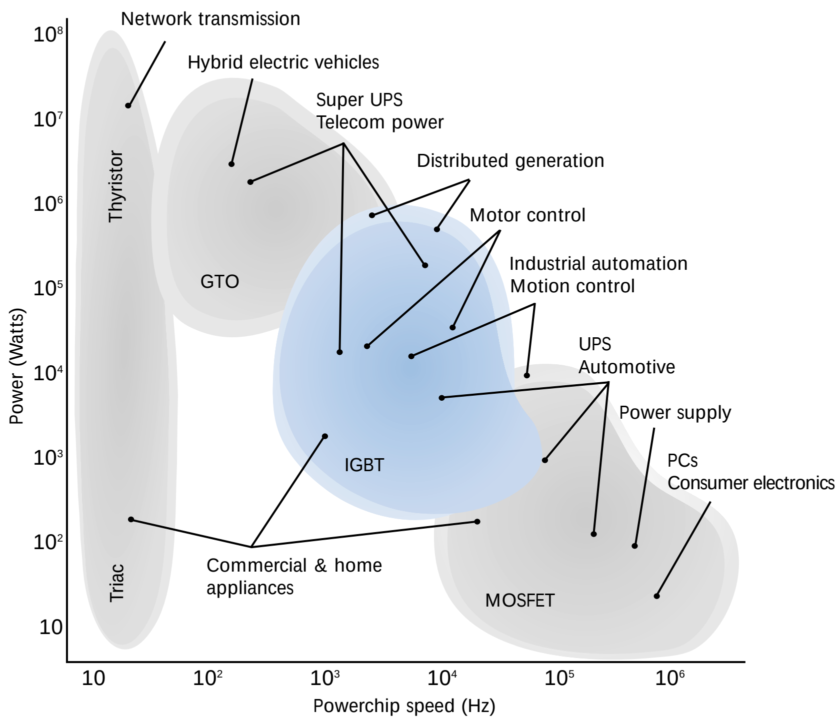
Clean Power Systems take care of blips lasting from milliseconds up to about a second. Ride-Through Systems take care of events lasting seconds to minutes, and occasionally hours.

Most home and small office PCs already use the increasingly ubiquitous American Power Conversion products which use a battery (controlled by powerchips) that can keep your PC up for several minutes if the power hiccups.

A dot-com or net-bank with a power appetite hundreds or thousands of times greater may use enormous banks of batteries for ride-through. Batteries present maintenance, reliability, and longevity constraints that have not fundamentally improved in decades. But they are now responding to dot-com needs, as new materials and computer-aided design capabilities are finally beginning to yield real progress.

Most power secure operations have two redundant battery banks. But an electromechanical flywheel can replace one, using one-tenth the floor space of batteries and requiring essentially zero maintenance. An electric motor runs, when there's power, to spin up to a one-ton steel flywheel. When the power fails, the motor reverses and becomes a generator, powered by the flywheel's inertia—good for 250 kW and more, for as long as it takes to power up the back-up generator. One of the early commercial installations of the Active Power flywheel was in the summer of 1999 for a Comcast's critical cable and Internet hub facility. With its August 2000 IPO, the flywheel solution is gaining traction. Active Power has partnered with Caterpillar, as well as such major UPS companies as Liebert and Power Ware.

Powerchip Hierarchy



Stand-Alone Local Generators

Electronics and batteries take care of the milliseconds and the minutes; beyond those lie the outages that last hours or days. On-premises generating capacity boosts the reliability of the power mainly by shortening the wire between the generator and the user.

We project a huge surge in demand for on-premises generators. The estimated world market today is $5 billion a year for diesel generators. Standard wisdom forecasts a tripling over the next five years. We think a ten-fold increase will be closer to the mark. The hockey stick will be driven by four factors.

1.The demand for High Nines power is altogether new; the digital Economy is here and growing.

2. The power electronics required to bring stand-by generators on line quickly and cleanly only matured in recent years. Safely and economically interfacing half-megawatt generators with the utility grid required switching gear that was almost impossible to find as recently as five years ago. It is readily available today.

3. The deregulation of the power industry is accelerating just as powerchips make deregulation relevant.

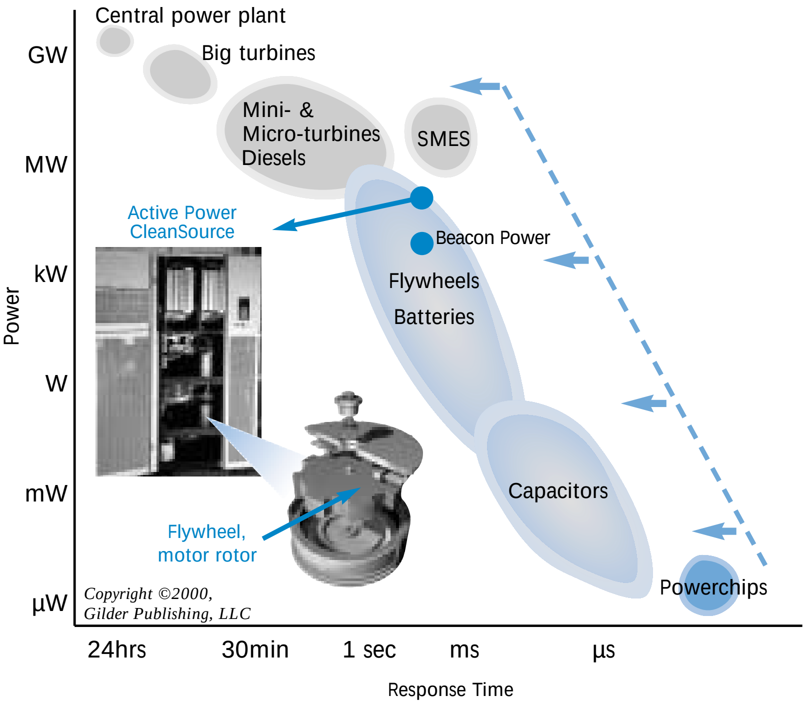
The deregulation of the electric market and the disassembly of the "natural" monopoly system began in earnest in 1992 with the Energy Policy Act that opened up competition at the wholesale level. Over one-half of all electricity produced at utility and merchant central station generating plants is already sold several times over, through broker contracts, before it is ultimately consumed. Now the retail side of deregulation is in full swing, with a majority of states under legislative "restucturing," or deregulated (except for transmission; more about this in future issues). Federal legislation is likely to accelerate the movement (despite California's recent stumbling approach to deregulation that has proven only that it is possible to get it wrong).

4. The stealth revolution in materials science and engineering for diesel engines has almost doubled efficiency and boosted reliability. A 1981 Caterpillar 3500 series produced 900 kWh; the same block and geometry now produces 2,200 kWh. Similar benefits have accrued to turbines, generators, and the entire panapoly of hardware in power systems.

Powerchips are eliminating the mechanical governor, alternator and voltage regulator. Windows-compatible software controls startup, fuel economy, and voltage stability. Thin servers and neural networks allow real-time and remote monitoring and diagnostics, boosting reliability and dropping costs. In short, the venerable diesel has come a much longer way technologically than the much hyped windmill or fuel cell; and it's cheap.

And newly in the market are the mini- and micro-

Ride-through electrons



Powercosm technologies span a wide range of power levels and response times. Batteries, and now flywheels, provide ride-through power in the middle of the curve, where substantial amounts of power are required very fast, to keep racks of silicon lit during the grid's frequent dips.

turbines; tiny versions of airplane engines. Mini-turbines are already commercially viable (Capstone prominent among the players), poised to take market share as the monopoly regulatory structure unravels. On the horizon, a 100 pound machine producing 400 kW. Turbines like to run flat out round-the-clock. One thing dot-coms need, is lots of power round-the-clock.

All three of these technologies, Clean Power Systems, Ride-Through Systems, and Stand-Alone Local Generators, are practical only because of powerchips. Powerchips are as central to the transformation of the power industry as the microchip was to the transformation of the computer industry. Thus we put forward two propositions:

1. Solid-state devices will take over all power switching at all power levels and all speeds. And it will happen far faster than most analysts suppose. Powerchips will permeate the grid, from the central power station down to the motherboard.

2. As powerchips proliferate, they will expose the entire generating and service infrastructure of the conventional power industry to competition. A tidal wave of new storage and generating alternatives will respond to a huge reservoir of unmet demand for High Nines power. In so doing, they will thrust competition into the bowels of the industry, and transform it beyond recognition.

The Implications for Utilities

The powerchip will disrupt established utilities in much the same way as the smart chip disrupted the mainframe industries, except that this time there is more to disrupt. Smart chips arrived just two decades after the mainframe; the powerchip arrives to disrupt an electric utility business that has been growing for more than a century. It is coincidentally an industry now poised on the brink of enormous collateral disruption by regulators.

The worst utilities will go the way of Pan Am. Or the way of Digital Equipment, or Control Data, Wang, Burroughs, Univac, Tandem, Data General, or Prime. Over time—and huge though they are—they will see their core businesses wither and vanish. Others will limp along, the way of a TWA or a Continental. A third group, the IBM equivalents, will get smart or lucky. And there will be a fourth group, new entrants that don't exist today, the equivalent of America West, or Dell, or AOL, that will build up from scratch, seize new opportunities, and prosper.

The weak players will be destroyed by a technological pincer movement. Their base of Three-Nines commodity kWhs will be stolen by more efficient providers transporting electrons on upgraded or new backbones. At the same time, peak loads—and peak prices and margins—will be flattened by back-up generation systems whose owners start wheeling their excess power back on to the grid. Most back-up systems, installed to support High Nines quality, will run too expensively to make it worth while to wheel their power back on to the grid—most of the time. But when spot prices spike they will be there to pick up some of the windfall that now goes strictly to the utilities. Even more likely they will find it profitable to leave their systems up and sell High Nines power to other nearby smart chip companies.

As the number of local generators grows, installed originally to provide High Nines insurance to their owners, the architecture of the grid itself will begin to change. Rather than a series of virtually identical Three Nines plugs, the grid will take on a lego-block architecture: with a variety of components highly adapted to different functions, yet also standardized and perfectly interconnectable, analogous to both the fragmentation and the interoperability of telecommunications networks. The forces of dispersion are by no means identical, but the main currents are the same: new interfaces, made possible by new switches and new 'pipes', that permit competition to get established all around the periphery of the old monopoly network.

Once established, competition will inevitably bore its way inward. Clean, 100 to 1000 kW diesel generators, mini- and micro-turbines will first become standard fixtures alongside the buildings that house ISPs, dot-coms and network POPs. Not long thereafter they will appear in every other major business and factory, and finally in apartment buildings and residential developments.

How soon will this market be significant? Today more than 95% of all electricity consumed comes from utility sources. The nation's grid has about 760,000 MW of capacity. About 10%—some 80,000 MW—is used ("dispatched") only hours per year to support Three Nines grid reliability.

Sitting off the grid, uncounted by the official counters, and unnoticed by ordinary rate-payers—there already stands another 80,000 MW or so of non-utility standby-generating capacity. It too is on only hours a year—right now.

None of this capacity is included in official government data, appropriately enough since the raw capacity figures do not begin to tell the whole story:

1. This capacity is privately owned; it is entirely free of price regulation.
2. Nevertheless, when regulatory conditions are favorable, it can pump power back into the grid, for sale to others.
3. It offers short-wire, Six Nines reliability and can command prices and margins to match.

The first two factors alone would spur very healthy growth in generator sales. But the third will push things way over the top. All the standard projections about the prospects in this market are far too low, underestimating both the progress in powerchip technology, permitting the efficient and safe interfacing of small generators with the grid, and the demands of smart chips.

Half of the electric system will be anchored in the digital Economy within the next decade. The last government report that comes close to assessing IT-driven kWh demand was published in 1995. At that time, the study estimated computers and faxes in commercial buildings accounted for about 3.5% of U.S. electricity demand. (This is comparable to the total electricity output of Taiwan.) That was five Internet years ago. In 1998, U.S. electric supply rose nearly 4%, roughly twice what forecasters had predicted. If that number sounds small in the hyperbolic world of the Internet, recall that is calculated against an enormous denominator, a full century of accumulated demand from other applications.

That's why we certainly don't predict the demise of most utilities, nor of their big central power stations. In fact, we predict the opposite. The Pan Ams of the industry will fold, but the industry as a whole will prosper and grow. A decade or so ago, mainframes were being written off entirely; even IBM was supposed to be headed nowhere because of the PC. Yet today there are 60,000 more mainframes running in the U.S. The best utilities are on IBM-like trajectories of their own. Dispersion and duplication of power supplies won't kill the central power plant, no more than it killed the mainframe.

A New Power Paradigm

Whether in telecom, computing, or the power industry it is new interfaces and interconnections that undermine monopolies and replace them with vibrantly competitive new marketplaces. In telecom, four generations of regulatory and technological change created new interfaces between the phone line and the "customer premises equipment," the local switch and the long-distance network, the local switch and wireless network, and—more recently—between the local switches of "incumbent" and "competitive" local phone companies. The result has been to transform a sleepy utility sector long dominated by one "Grandma" stock into the central nervous system of a new economy and the most vibrant of investment sectors.

Just up the street, the powerchip is now coming of age. It will create affordable, reliable interfaces between a constellation of new sources of electric power, from batteries to diesel generators, from flywheels to turbines, transforming ducklings as ugly as thousand-pound flywheels and reciprocating diesel generators into the swans of High Nines power. It creates the clean interface between musty basement and greasy coverall-clad building engineer, and the clean room of the chip fab or server factory.

Empowered by the powerchip, these technologies can collectively deliver the power of the information age with a standard of reliability so far beyond the capabilities of the old grid that it defines a new market, and a constellation of new industries with glittering margins.

At first this new constellation may seem a hopeless confusion of uncatalogued albeit possibly combustive opportunities. But every investment opportunity in the market for Internet Economy power can be analyzed by reference to three questions:

• Does the company contribute crucially and competitively to the function of the switch, the powerchip itself?

• Or is it an integral part of the distributed storage and generating opportunities that the powerchip empowers?

• Does it deliver High Nines competitively?

Among the companies that fit that profile there will be better and worse. But when a new, disruptive technology like powerchips, or smart chips before it, first begins to redefine an industry or an era, the resulting updraft can render trivial reams of the workaday analysis so crucial in more ordinary circumstances. Powerchips yield a technological and investment paradigm of great clarity and enormous power, an alternate and, happily, lesser-known path to the vital center of the information economy, the exploration of which is the central purpose of the monthly

Power Panel Companies in 2000

Powerchips

IGBTs

International Rectifier (IRF) www.internationalrectifier.com
International Rectifier fits the powerchip paradigm very closely with strengths in the key middle-power, high-speed market, manufacturing powerchips on state-of-the-art facilities, free-riding on the manufacturing technologies of the smart chip industries. With the experience, technology, and market credibility to push silicon up the power curve, International Rectifier is the venerable pioneer in solid-state switches. Increases in speed, together with complementary improvements in architectures and materials are now pushing up the company's powerchip module densities by 30 percent every 2 years. Like IXYS, International Rectifier also serves significant markets in lower-power (MOSFET) powerchips, which are also pushing even higher and faster up the speed curve. Also like IXYS, IRF is well established on the power curve. It has been in business for years, is now a direct, free-riding beneficiary of extraordinary advances in silicon material procession and silicon wafer engineering, and will continue to be the unintended but direct beneficiary of every major advance in silicon science and silicon-wafer engineering.

IXYS (SYXI) www.ixys.com
IXYS manufactures IGTBs that started at only a few kHz, reaching now into the high-speed stratosphere going beyond 100 kW. IXYS just announced a new IGBT architecture, a reverse blocking IGBT (RIGBT) that has the potential to eliminate up to two-thirds of the physical components in front end power management. A standard IGBT can block power flow in only one direction; the RIGBT blocks in both, which makes it ideal for operating in an alternating current environment. IXYS already sees over one-third of its powerchip business going into the telecosm. IXYS also serves significant markets in lower-power (MOSFET) powerchips, which, too, are pushing even higher and faster up the speed curve. But IGBTs represent the company's largest untapped markets. IXYS is close to a pure play in powerchips generally and as pure as the plays come in the medium and high-power level IGBTs. IXYS is well established on the power curve. It did not have to develop the silicon foundries, aligners, photolithography machines, and other equipment: the smart chip fabs did that for it, but it is now a direct and free-riding beneficiary of extraordinary advances in silicon material procession and silicon wafer engineering.

Advanced Power (APTI) www.advancedpower.com
Advanced Power is another pure play in the realm of insulated-gate bipolar transistors, one that only entered the public domain a few months ago. Well up into the critical power level and deep into the high-power end of the Powercosm, Advanced Power serves automotive and industrial markets up into the ultra-high power utility network grade powerchips from Powerex (A GE-Mitsubishi joint effort, www.pwrx.com)

Ghz Power

RF Powerchips: LDMOS

UltraRF (SPCT)** (UltraRF is currently a subsidiary of Spectrian that is expected to be purchased by CREE (CREE) before the end of January 2001) www.ultrarf.com
UltraRF, a wholly owned semiconductor subsidiary of Spectrian, is going to give the big guys in the industry a run for their money. UltraRF has developed the 60 W UltraGold II, a high-power CDMA (code division multiple access)-focused LMDOS cell architecture, coming up with a unique geometry to accommodate the power swings of CDMA—style modulation, and to overcome laterally diffused metal-oxide-semiconductor's (LDMOS's) inefficiency when operating off-peak power. At the critical emerging 2 GHz frequency, UltraRF stands essentially alone today as a third player, and, hopefully, as a soon-to-be independent source. UltraRF has a solid history in RF (radio frequency) amplifiers, and has developed ways to change the height of the wires that bond the already flat chip depending on whether it is destined for 1800 MHz, 1900 MHz, or 2100 MHz applications. Many RF chips employ

aluminum, but not any of UltraRF's chips. Alone in the industry, UltraRF has mastered the operation of a fully integrated LDMOS Gold/MOS fab. Ultra RF is a relatively small company, and faces much larger established competitors. But it has ingenious designs, deep history, and critical intellectual capital, as well as a line-up of very significant customers. If it does emerge as a fully independent vendor of high-frequency high power RF powerchips it will be perfectly positioned to become a major supplier to the numerous manufacturers of RF power amplifiers that will be building for the vast new market of third generation broadband wireless.

Network Transmission and UPS

High-temperature superconductors

American Superconductor (AMSC) www.amsuper.com
One of the leading manufacturers of local-area grid and substation level superconducting wires and components, American Superconductor manufactures bisco ("bismuth-strontium-calcium-copper oxide" which takes the place of copper in electron networks) and builds things with it. "Superconductor" brings to mind long wires, but the main use for AMSC's wires is in substation components. Among other things, AMSC builds wave-suppressing devices for grid-scale waves. AMSC's principal customers are utilities, along with large Powercosm customers that have megawatt-scale loads. Both are now using AMSC's technology to push their power control nodes into this century. AMSC has developed solid-state power converters that can bridge the divide between AC and DC—converters capable of switching megawatts of power in microseconds. These extremely fast, high-power units are built around insulated gate bi-polar transistors (IGBTs) and the integrated gate commutated thyristor (IGCT). AMSC's high-end powerchip control systems will find applications in high-power private "grids" of every description.

ABB (As of this publication, ABB's listing on the NYSE is pending) www.abb.com
ABB is a global leader in the manufacture of substation components, grid operations, and the contract design and engineering of entire substations. This 25$ billion-a-year company is both the world's leading manufacturer of many substation components and the leading integrator of complete substation solutions. ABB also owns the power industry's only counterpart to Bell Labs—a $2 billion/year research operation and now ranks as the world's leading developer of grid hardware, and the owner of the most sophisticated software assets required to add logic intelligently to high-power grids. ABB manufactures powerchip modules, and wide range of substation components, as well as sealed, gas-insulated switchgear that has a dramatically smaller footprint a lot more reliability than the conventional air insulated alternatives. With $2 billion in sales, it is the largest transformer manufacturer in the world. At the most fundamental level, ABB is in the business of caching power and switching it intelligently.

Electron Storage and Ride-Through

Flywheels

Active Power (ACPW) www.activepower.com
For stationary ride-through applications in rooms and buildings—in the hundred kW to multi-MW level ranges—the right flywheel is better than a battery, and Active Power has the right flywheel. In Active Power's CleanSource, an array of IGBTs keeps the voltage rock-steady at 480 V DC, the gold standard of the Powercosm. CleanSource also has a separate 24 V output, which can back-up or replace the standard 24 V battery required to start a backup generator—battery failure is the single most common reason for the failure of back-up power. Active Power's powerchips recapture 94% of the stored kinetic energy and deliver 80% of it to the load. Older designs could only use the top 5% or so of the flywheel's energy before the frequency and voltage decayed unusable levels. Today is a time of soaring demand for just what Active offers: a robust, commercially proven product of elegant design, built from just the right technology, and surrounded by a reasonable (though hardly impregnable) picket fence of patents. Active Power's genius doesn't lie in wildly new technology; it lies in elegant design and perfectly timed execution.

Beacon Power (BCON) www.beaconpower.com
The only manufacturer of high-speed flywheels to have made a commercial sale is Beacon, whose 200-pound carbon fiber flywheel spins at 20,000 rpm. Beacon is building a stationary platform, targeting battery replacement, and aiming to provide energy storage on top of ride-through in places where the flywheel's edge over batteries centers on transparency, durability, and reliable remote monitoring. Beacon's flywheels are configured to provide several kWh of continuous power, for up to several hours, for distributed end-point telecom applications where the unreliability and maintenance demands of battery systems are a serious liability. Beacon has made consistently good calls in engineering design and market targeting. Its package fits in an oil-drum-sized vacuum container, and is being deployed in places where it can be buried—which takes care of all lingering concern about safety. Beacon's buried flywheel offers the promise of zero maintenance, 100 percent operational transparency, and easy remote monitoring.

Hydrogen Generation

Proton Energy Systems (PRTN) www.protonenergy.com
Proton Energy Systems has developed the most interesting hydrogen generating technology we've come across and they are already selling viable hydrogen generation equipment for the industrial market. Proton's hydrogen generation unit, HOGEN, looks much like a dishwasher on steroids; white, some buttons and gauges, a few connections. Water and electricity go in, 99.999% pure hydrogen and oxygen come out and without a trace of membrane killing carbon or carbon monoxide. No noise, no chemicals, no pressure system. Ironically, the unit once again houses a proton exchange membrane (PEM), but run this way the PEM is enormously reliable. Industrial, chemical, and laboratory, users spend $1.5 billion a year on hydrogen, and the HOGEN can deliver it at one-thirtieth the cost of hydrogen in cylinders, and from a much more convenient, toaster sized unit. Proton's HOGEN, or a unit much like it, could be what it takes to someday make sense out of the most over-hyped but least reliable fuels on the landscape, the sun and the wind.

Silicon Power Plants
In-the-room AC and DC

Emerson (EMR) www.emersonelectric.com
Leading the small handful of companies that are going to own the market for the new, high-9s power plant, Emerson is effectively sold out of the high-end power plants in 600 kW-plus sizes; a single Powercosm Hotel could gobble a couple of dozen. Its delivery backlog for such units was six to eight weeks not long ago; it is eighteen to twenty weeks today. Orders have doubled in the past year alone. The company's bottleneck is now building out space fast enough to manufacture more. Emerson is the largest company in its market with 23% of the global business in the AC side. One of only two companies that can be said to be aiming squarely to dominate power plant space, Emerson has a high-end power plant unit, Helios, that operates at under 5 percent total harmonic distortion (THD). Emerson has the corporate sales of $350 million in AC UPS and $500 million sales in DC power plants. Much of Emerson's most valuable intellectual property resides in its engineering history, and the real-world experience Emerson reflects. Emerson ranks far ahead of the rest of the field, with approximately one-third of its $15 billion annual sales realized in these key markets.

Power Plants

Power-One (PWER) www.power-one.com
The other of the two companies aiming squarely to dominate the DC power plant space is Power-One, a company also on our Power Panel for its ascendant brick technology. Power-One, a company coming to the Powercosm Hotel space firmly anchored in DC competency, has a power plant unit, "Densepack" that operates at under 5 percent total harmonic distortion (THD).

Motherboard Power

Bricks, High end DC/DC converters

Power-One (PWER) www.power-one.com

Power-One is now aggressively pushing silicon-centered technology up the power curve, down the cost curve, and into a commanding position among companies that power the digital infrastructure. It stands an excellent chance of emerging as the leading company managing the routing of big electron flows at the building level and on down, a Cisco of the Powercosm. In a Powercosm version of Moore's Law, Power-One has been cutting the size of bricks in half every two years for a constant power output. Power-One engineers expect MOSFETs, and thus bricks, to be running at 2 to 3 MHz speeds within two years. Power-One holds patents on a sealed, planar transformer. This makes possible the first "non-potted" washable brick. It eliminates the need to seal the entire brick in a black polymer shell to protect the transformer during washing to remove soldering residue. The MOSFET-based "open frame" approach further improves cooling. Power-One has the broadest, and most diversified, line of high-power bricks; with their new product line, they now have a model line-up 50 percent bigger than Lucent or Ericsson. Power-One is also the fastest growing, and the largest, pure play in its area.

Distributed Power Generation

Microturbines

Capstone Turbine Corp. (CPST) www.capstoneturbine.com

The Capstone microturbine is a fantastically reliable, clean, compact, simple—in some respects "dumb"—device, made possible by uniquely smart digital logic alongside. Capstone's microturbines generating 30 kW and weighing a paltry 1,082 pounds fit the bill for the huge number of sites that represent loads in the 30-600 kW range. It would take one hundred of them just to power the water-coolant pumps in the big coal and nuclear plants that ABB used to engineer. A unique and ingenious feature of Capstone's turbine is that when the grid is up, the silicon auto-synchronizes with it—the power electronics were designed from the start to do so. This makes for perfectly seamless connection to, or disconnection from, the grid. Capstone alone has likewise completely eliminated liquid coolants, from both turbine and generator. This is not just another small back-up generator, it is a quintessential 9s machine, more compact, quiet, clean, mechanically reliable and electrically stable than anything that has come before. Capstone is perfectly positioned as a leading-edge disrupter in the expanding new cosmos of the electron.

Fuel Cells

FuelCell Energy (FCEL) www.fuelcellenergy.com

All fuel cell technologies, FuelCell's included, are long term. By listening to the technology, however, FuelCell has positioned itself on the shorter end of the long term. FuelCell's carbonate unit reacts with natural gas with steam, and the company brags that the unit can feed on natural gas, marine diesel fuel, and even gasified coal. None of this endears FuelCell to the greens. What endears FuelCell to us is that its technology works, and works reliably, it appears, for tens of thousands of hours. FuelCell's Direct Fuel Cell (DFC) units are compact enough as megawatt-level power plants go. The units take 20 hours to preheat, but they can easily be maintained on hot standby, using under 0.5% of their full-load fuel. FuelCell's basic, four-stack can produce 1,000 kW, which makes it a nicely sized building block in an uncrowded segment of the power curve. FuelCell is clearly on the right trajectory, and far ahead of the small-and-cool alternatives. Because it builds relatively simple systems, Fuel Cell's main technology edge lies in the raw know-how of engineering robust boxes. Fuel cells that add reliability are going to be big-and-hot, like FuelCell Energies DFC, or very small, along the lines of the Hockaday cell.

Power: Heavy-Iron Lite

General Electric (GE) www.ge.com

General Electric is the IBM of big electrons. Overall, GE turbines account for an estimated 30 percent of current U.S. electric capacity, and some 60-80 percent of all new capacity ordered or planned. With a long tradition of supplying heavy iron to heavy-footed utilities, GE has the largest installed base of power generation in the world. More important, GE dominates (60 percent market share) today's North American market for aeroderivative turbines in the heavy-iron sweet spot, the 15-60 MW range. GE knows how to evolve and is clearly determined to do so. No other company is comparably positioned to squeeze digital quality power from powerchips, fuel cells, superconducting coils and turbines—or to bring digital capabilities to lights, refrigerators, stoves, compressors, and machines of every description. Overall, there are some 6,300 GE-designed gas turbines now installed or on order worldwide. Having seized the lead in simple-cycle engines for jumbo jets, GE established an early lead in the combined-cycle terrestrial market, which it has never surrendered.

Catalytica (CESI) www.catalyticainc.com

When it comes to squaring megawatt-scale gas turbines with clean air, Catalytica has the solution in its revolutionary "Xonon" technology. The best thing that big fuel cells have going for them is the free pass they get from green regulators, which they receive largely because they emit no nitrogen oxide. Catalytica's "Xonon ("no Nox," backwards) Cool Combustion" technology accomplishes this in turbines by putting a palladium up front which separates the carbon from the hydrogen causing a low-temperature burn of carbon into carbon dioxide outside the fuel cell, and hydrogen into water inside it. Best of all, Xonon technology doesn't degrade turbine efficiency. Though headed initially for much larger and smaller turbines, Catalytica now is principally targeting the heavy-lite middle of the turbine market. It has set the stage to work directly with most of the major turbine vendors on an OEM basis. For internal production, Catalytica has developed 3,000 sq ft manufacturing cells, each capable of producing 1,000 Xonon modules a year. The cells are scaleable, and Xonon intends to locate them, as well, on the factory floors of its main turbine customers.

Micropower

Nano-fuel cells

Manhattan Scientifics (MHTX) www.manhattanscientifics.com

While FuelCell Energy has a "big and hot" battery that generates 1,000 kW of power and comes in a can 12' high and 12' around, Manhattan Scientifics is doing some promising work with a nano-fuel cell plant, one millionth the power (1 W) and the size of a credit card. Manhattan Scientifics' nano-cell creator Bob Hockaday has followed the PEM membrane to where the technology's underlying physics inexorably leads. If it works commercially—as it already has in the lab—the Hockaday cell could end up providing a whole lot of portable electrons to the wireless Telecosm. Hockaday built a very small system, which makes it inherently sturdy. Inertial and thermal stresses are lower in smaller systems, so membranes last longer. The cell runs at room temperature, which is where the delicate membranes want to operate if they're going to last. And it runs on a readily available carbon fuel—methanol. Hockaday deals with the still remaining problem of carbon monoxide in the cell by adding still more catalyst inside the fuel cell itself—ruthenium oxide, which immediately converts the CO to harmless CO2 before it can corrupt the platinum alongside

This special report was first published in September 1999 and updated in December 2000 by the editors of the *Huber-Mills Digital Power Report*.

The Digital Power Report is published monthly by Gilder Publishing, LLC. Editorial and Business address: P.O. Box 660, Monument Mills, Housatonic, MA 01236. Editorial inquiries can be sent to: peterhuber@gildertech.com or markmills@gildertech.com. Single-issue price: $50. For subscription information, call 800.261.5309, e-mail us at help@gildertech.com, or visit our website at www.Powercosm.com

THE HUBER MILLS digital power report