THE HUBER MILLS digital power report

Powering the 21st Century

SPECIAL REPORT

Published by Gilder Publishing, LLC

The National Energy Policy Development Plan: A Technology Investment Perspective

Nearly $500 billion per year are invested annually in U.S. power and energy technologies

Two weeks after the inauguration, the Bush administration established the National Energy Policy Development Group (NEPD) with a mandate to develop a statement of national energy plans and priorities. The group's 200-page report was issued in May 2001 and has generated weekly, if not daily, commentary and reaction. If there was any remaining doubt before, there is none now: energy is front and center on the national agenda.

Clearly, energy has become an important *political* issue. More importantly, however, this is not a made-in-Washington crisis, here today but probably gone tomorrow. There are fundamental economic and technological challenges to be addressed. They are going to be at the center of a lot *economic* activity for the foreseeable future.

Why now? First, because energy in general, and electric power in particular, have been ignored (at best) or undermined by wishful thinking and short-sighted policy for most of the last decade. Policy makers have been indifferent or foolish; investors have been indifferent or hostile. As a result, we've managed to dig some deep holes, most notably in California.

Second, because the character of electric demand has changed. As we have been emphasizing now for two years–the digital world has created a new kind of demand for a different kind of power–high-9s power, power available more than 99.9999 percent of the time, good enough for microprocessors and packet switches, not just toasters and light bulbs. But at the same time, a separate cluster of demands, from environmental regulators, place increasingly tight constraints on the fuels and technologies we use to supply power.

And third, because there have been recent, remarkable advances in power technologies. Though they emerged two decades later, and remain overshadowed (at least in the public eye) by the technologies of bits, the technologies of electrons–of power–are now advancing as fast. Power technologies that have been quietly incubating for a decade or more are now coming of age and bursting into the marketplace. We have not seen anything quite so fundamental or exciting since the rise of telecom and datacom technologies nearly two decades ago.

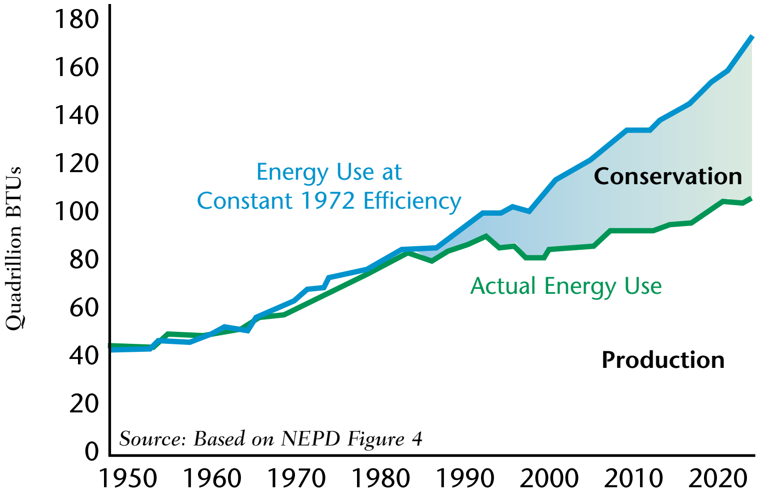
Produce and Conserve

The early pages of the NEPD include a graph (NEPD fig. 4) that encapsulates the challenges, and the two basic responses, that lie ahead. If energy consumption continues to rise in proportion to GDP, it will rise fast (the upper curve). However, if we continue to get more efficient in our use of energy–as we have done since the dawn of the industrial age–then energy consumption will still rise, just not as fast as GDP (the lower curve).

Debate pivots around the ostensibly conflicting imperatives of producing more energy, and encouraging more conservation.

We will in fact do both. Both tracks present a wide range of new opportunities in technology, and consequently new investment opportunities.

U.S. Primary Energy Use



Source: Based on NEPD Figure 4

Production

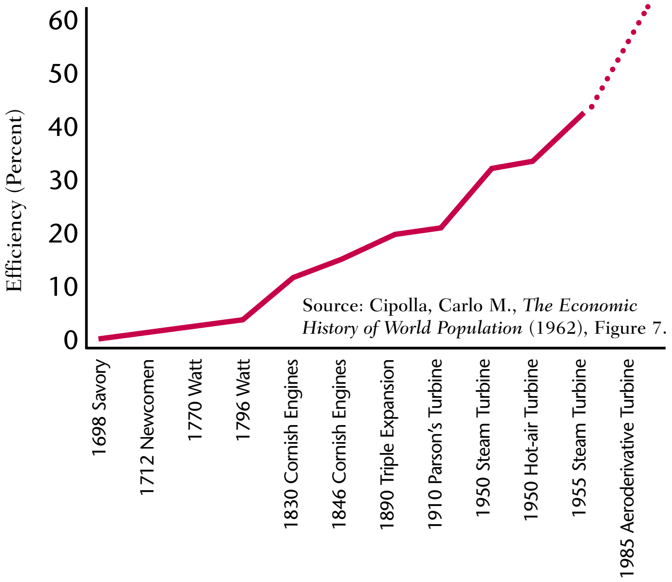
Our consumption of primary thermal fuels rises. It has risen throughout human history, and it will continue to rise for the foreseeable future, however clever and diligent we may be with efficiency and conservation. We know of no serious mainstream observer who believes otherwise.

Energy consumption *per capita* may grow more slowly, particularly as demographic changes shift us toward a more elderly population. Energy *per unit of GDP* has declined throughout human history, and will continue to decline. But total energy consumption has nonetheless risen, and will continue to rise. Consider just one, clear example of this seeming contradiction; the history of efficiency gains in engines compared to total commercial aviation fuel consumed (passenger plus freight).

This reality points inevitably to the continued importance of production technologies, all of which can be grouped into three classes: extraction being the largest (e.g., oil wells and pipelines), followed by fuels chemistry (e.g., refineries), and then the so-called renewables–primarily solar and wind.

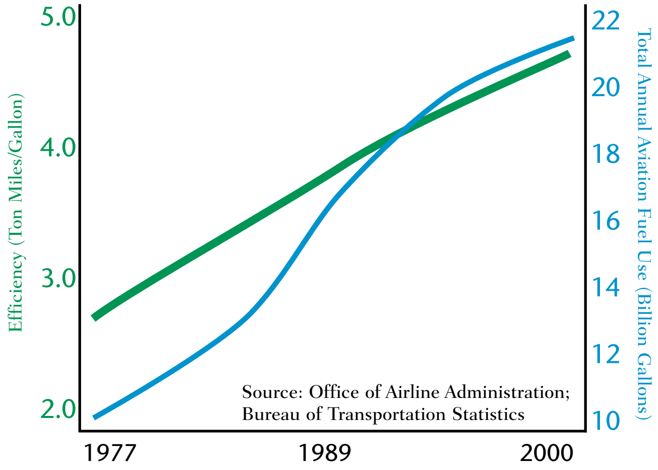
The production portion of the story centers mainly on large established players in heavy industries–the likes of Exxon-Mobil (oil and gas), Massey (coal), Louis Dreyfuss NG (natural gas), Cameco (uranium), and other large companies such as Sunoco that are engaged in refining, and players such as DuPont, which are in the corollary activity, emissions control.

History of Engine Efficiency



Source: Cipolla, Carlo M., *The Economic History of World Population* (1962), Figure 7.

Jet Engine: Efficiency & Fuel Use



Source: Office of Airline Administration; Bureau of Transportation Statistics

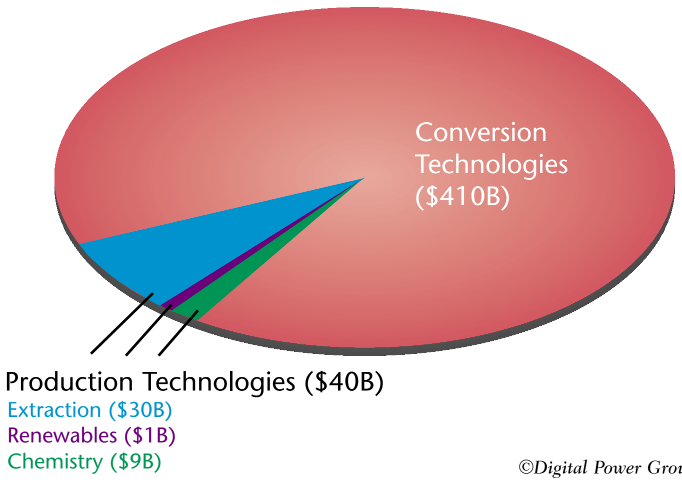
The space also includes a number of smaller companies developing technologies that are powered by wind, solar, and other "renewables."

There has been and will continue to be a tremendous technological opportunity across the board in the production and extraction of raw fuels. Twenty years ago, for example, an article in *Science* predicted that by now we would have to be drilling so many wells so deep into the ground that it would take more energy to get out a barrel of oil than is contained in

Editors Peter W. Huber
Mark P. Mills
Publisher Lauryn Franzoni
Associate Editor Keri Geiger
Designer Julie Ward
President Mark T. Ziebarth
Chairman George Gilder

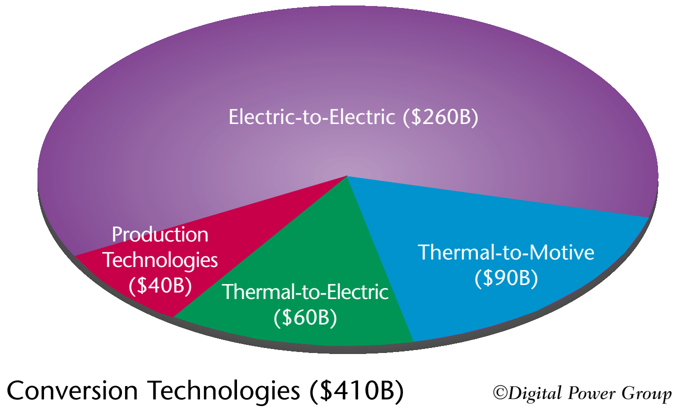
The Digital Power Report is published monthly by Gilder Publishing, LLC. Editorial and Business address: 291A Main Street, Great Barrington, MA 01230. Copyright 2001, Gilder Publishing, LLC. Editorial inquiries can be sent to: peterhuber@gilder.com or markmills@gilder.com. Single-issue price: $50. For subscription information, call 800.261.5309, e-mail us at hmpowerreport@gilder.com, or visit our website at www.digitalpowerreport.com

Annual Capital Spending on Energy Technologies



©Digital Power Group

Annual Capital Spending on Energy Technologies



©Digital Power Group

the barrel of oil itself. ("Petroleum Drilling and Production in the United States," *Science*, 6 February 1981, p 576–578.) That prophecy has not been fulfilled. Because our ability to locate oil and drill efficiently for it has improved dramatically (including horizontal drilling, just one of many possibilities simply not considered by earlier pessimists).

Within the $40 billion annual capital spent in the production sector itself, we estimate that roughly 75 percent of investment will go into what we call the extractive industries, with the chemistry piece attracting a little over 20 percent, and renewables accounting for a remaining few percent. But more important than our estimates of investment activity in each subsector is our estimate of the production sector's contribution to the entire energy sphere. To our minds, production represents only a little less than 10 percent of the entire technology and capital investment story in power. So where is the rest?

Conversion and Conservation

Almost everything that is in the nature of energy *conversion* technology will henceforth be renamed "conservation." Political imperatives certainly favor cynical semantic gamesmanship here, but the most important "conservation" and "efficiency" opportunities are indeed to be found at the interfaces, where energy is converted from one basic form to another. And happily for politician and investor alike, the technologies of energy conversion are now changing fundamentally, and advancing rapidly.

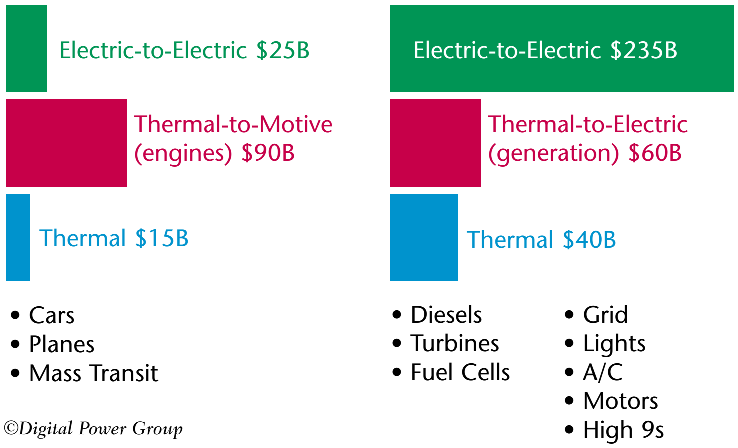
There are three main types of conversion: *Thermal-to-motive*–in a car engine, for example, or the gas turbine under the wing of a jumbo jet. *Thermal-to-electric*–in an electric power plant, or in the integrated alternator/starter motor of a hybrid electric car. And *electric-to-electric*–in the length of the grid, and throughout the end-user technologies, in motors, light bulbs, and toasters, for example, where the final conversion moves things back down the staircase, to motion and ultimately to waste heat. "High-9s" power conversion technologies also land in this group (the technologies that add reliability to electron supply from motherboard to manufacturing plant).

Most of the investment (over $400 billion/year) and innovation of our energy economy happens at these three interfaces. However efficient they may be, conversions are not in fact long-run substitutes for more primary production. But they are often perceived to be in the short run, on the theory that more efficient conversion means less waste, and thus less demand for primary energy. The fallacy is that more efficient conversion effectively *lowers* the perceived price of energy, which historically at least, has always translated into more consumption, not less, over the long term. But this is beside the point; for both political and economic purposes, more efficiency is better than less.

Within the conversion sectors, the first step up the energy staircase is the conversion of thermal energy into motion–moving planes, trains and autos, or moving shafts to spin electric generators in power plants. The annual investment in converting thermal energy to motive power dwarfs capital spent in extracting (refining, moving) the primary thermal energy.

Cars represent an enormous investment in thermal energy conversion technology–bigger in fact than just about anything else on the scene. The electric power infrastructure (thermal-to-electric conversion) is also

Annual Investment in Energy Conversion Technologies



©Digital Power Group

very large and represents a great deal of new investment. But this segment, though large, is actually smaller than annual investment (thermal-to-motive) in the power systems for cars, trucks, and aircraft.

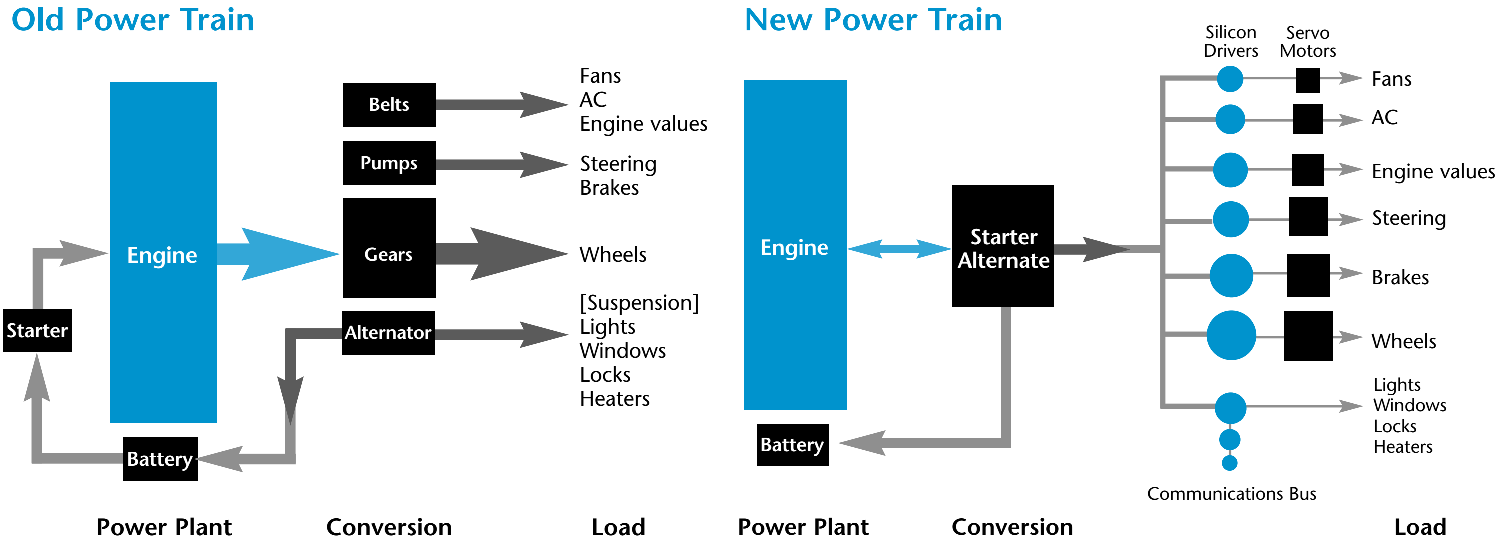
Although not usually expressed in these terms, the U.S. auto industry alone annually installs more thermal-to-motive conversion capacity in its engines than is represented by the entire installed base of thermal electric generators in the U.S. electric grid. The automotive sector presents a concomitantly large opportunity for investment.

Thermal-to-Motive Conversions. The thermal-to-motive conversion is the first half of almost all electricity generation, and represents almost the entirety of the energy conversion process (as opposed to capital spending) in transportation. In both areas, there is now rapid innovation, and aggressive investment, in new silicon technologies.

The innovation is centered on two technologies, both of them rooted in silicon: the silicon microprocessor—which has received much attention–and which of course spawned the revolution in information. And the silicon powerchip, which has received far less attention, but has spawned an equally important revolution in power electronics.

The rise of power electronics is best illustrated in the transportation sector. Until now, the thermal-to-motive conversion under the hood of a car has been largely a click-click, bang-bang process, centered on mechanical transformations: pulleys, belts, gears, drive systems, and the other inefficient devices needed to convert the thermal energy inside the engine into motion. The $90 billion of capital invested in the hardware of transportation power (engines, transmission, drive train) greatly exceeds $260 billion in capital spending on electric power related hardware under the hood. This is about to change.

The fundamental change that's occurring under the hood of a car is not the replacement of the internal combustion engine itself with something else (fuel cells or flywheels or batteries, for example). The change is occurring just south of the engine, in what we have called the silicon power drive train. It is a revolution in which a rapidly rising fraction of the power of the spinning crankshaft is converted directly into electricity, and the electricity is used not only to supply a proliferating number of (highly visible) comforts and digital conveniences in the pas-


Old Power Train

New Power Train

©Digital Power Group

senger cabin, but also to power a broad range of new, less visible but more important devices that drive, steer, suspend, brake, heat, and cool the car (***DPR Special Report, December 2000, Powerchip Paradigm II: Broadband Power***).

This is the "hybrid" automobile. Hybrid because it is a largely seamless combination of the old internal combustion with the new silicon-controlled electric drive train. It delivers not only more efficiency than what it replaces, which makes it attractive to green regulators, but also far better performance. For example, a single $100 module containing the electronics to allow a car to be steered electrically–as some aircraft are flown now–can deliver far more responsive, accurate steering than existing hydraulic systems, and also add a half a mile per gallon of fuel efficiency per car. An electromagnetically activated valve train (as opposed to the standard mechanical systems) will deliver more performance in less space and will radically boost fuel efficiency. Shafts and chains will give way to silicon and wires. The hybrid car responds to green imperatives–but it is being developed now because it is profoundly *better*: it is more reliable, steers easier, rides more smoothly and stops more safely, and it will soon be cheaper too. Today's relatively small capital investment in automotive electrical systems is poised to grow rapidly and become the dominant place for technology progress and investment opportunity (***December 2000 DPR***).

The same fundamental changes are now occurring in factories. The old gear and pulley drives are rapidly being replaced with silicon driven power devices that allow manufacturers to cut more sharply, paint more finely and run a more reliable, more productive assembly line. Here again, energy efficiency will undoubtedly improve, so the transformation can be called conservation. But the change is a *conversion*, and it is impelled, first and foremost, by a quest for better performance up front, not greener objectives at the tail.

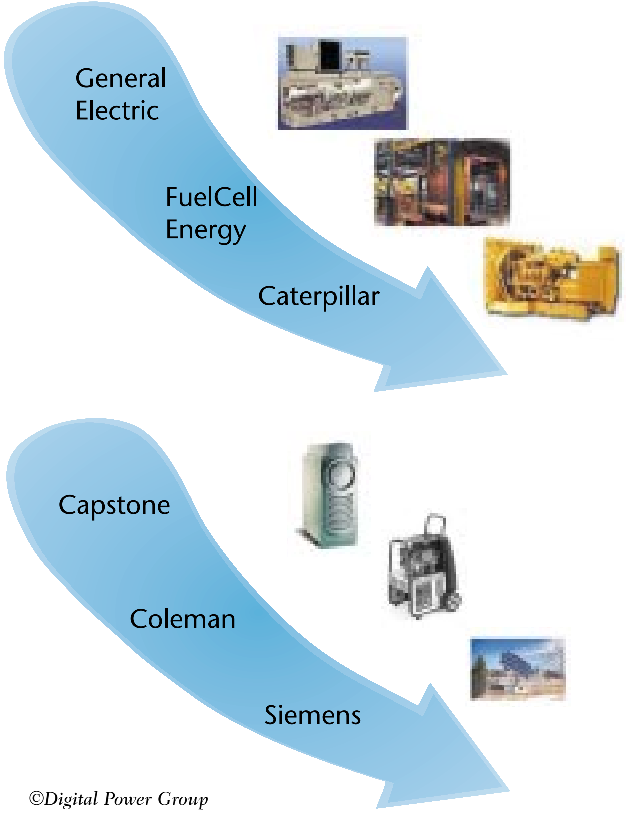
Thermal-to-Electric Conversions. The next paradigmatic energy conversion process centers on the transformation of thermal energy to electric. This is the more familiar space, of course, and it too is fundamentally a thermal-to-motive process (spinning shafts turning generators). In California, for example, the energy crisis that has dominated so much news has not been a "gas-lines" shortage affecting thermal-to-motive conversion in cars and trucks, but a "power-lines" shortage affecting thermal-to-electric conversion (albeit by way of moving generators) in electric power plants.

The technologies of thermal-to-electric conversions can be divided into two broad categories: central power stations, and distributed generation. The central-power sector includes large turbines (from companies like GE), utilities (AEP), large independent generators (Calpine), and companies like Enron that are essentially market makers (***October 2000 DPR***). The distributed generation sector includes both large and small companies, the makers of the relatively smaller reciprocating engines (e.g., Caterpillar), microturbines (e.g., Capstone), fuel cells (e.g., FuelCell Energy), and photovoltaic cells (e.g., Evergreen), that generate electricity. Distributed generation is the segment where most renewables are found (with the one exception of hydro power, the largest source of renewable energy, and the domain of big central utilities).

Firms operating in these two sectors do not typically compete against each other. Contrary to much that has been written, this is not, in the main, a zero-sum power game. Although they both generate electricity through the conversion of thermal energy, they mainly address two quite separate markets. Central station power plants generate low-cost and

---

Thermal-to-Electric: Electron Supply



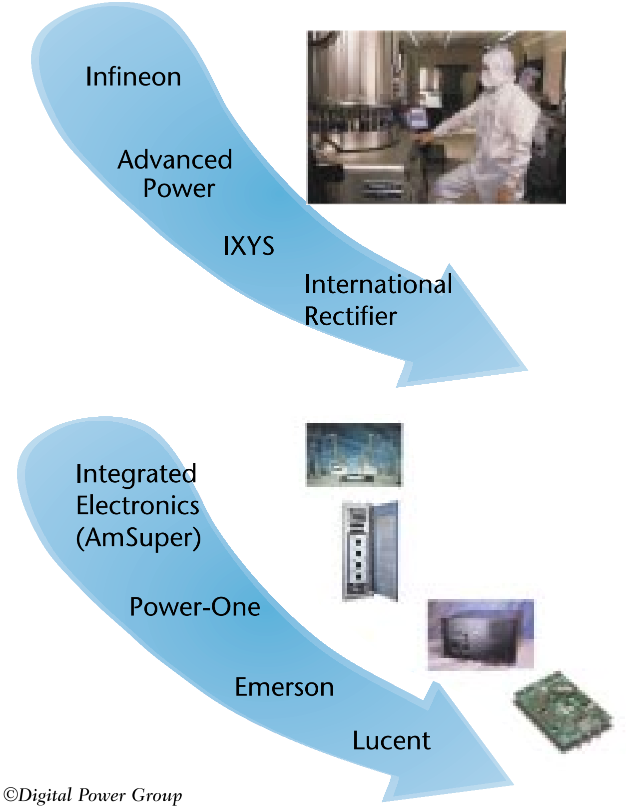
©Digital Power Group

relatively low “quality” wholesale electrons. Low cost because they are generated in very large, very efficient central stations; low quality because they are then delivered over very long, and thus relatively vulnerable power lines, and shared (often unpredictably and arbitrarily) within a large community.

Distributed generation technologies address a new imperative–the demand for reliability, i.e. power quality (***July 2000 DPR***). And the digital economy, for reasons tied to the sharp rise of datacom and telecom technologies that are ubiquitous from factory to silicon fab as well as communications systems, demands ever increasing levels of power reliability.

Electric-to-Electric Conversions. The broad range of technologies that we categorize as electric-to-electric can be grouped into two main sectors: the grid on the one hand, and all end-user electrically-powered technologies on the other. The grid distributes and shapes and moves the electrons from the generating source to the systems that use them. End-user devices include the refrigerators, lights, motors, and computers that run on electric power along with a broad class of related power conditioning technologies in everything from medical equipment to satellites, from factory motor controls to uninterruptible power systems. This broad category of power conversion markets represents the mother lode for investors ($260 billion in annual capital spending), and for those seeking to improve efficiency since this is where most power conversion occurs, and thus where the greatest opportunity for conversion efficiency resides. The former category–the grid from long wires to local neighborhoods–is a substantial capital and energy conversion sector. Power is converted up and down various voltage levels, routed, shaped and controlled, every step of which entails hardware with defined (and improvable) efficiency. Here annual capital spending has languished in recent years, but is still a substantial $40 billion annually (from city-level to building-level grids), and is poised to increase for practical and political reasons; much of the growth will occur in the new generation of high-power, silicon-based power electronics.

Electric-to-Electric: Electron Control



©Digital Power Group

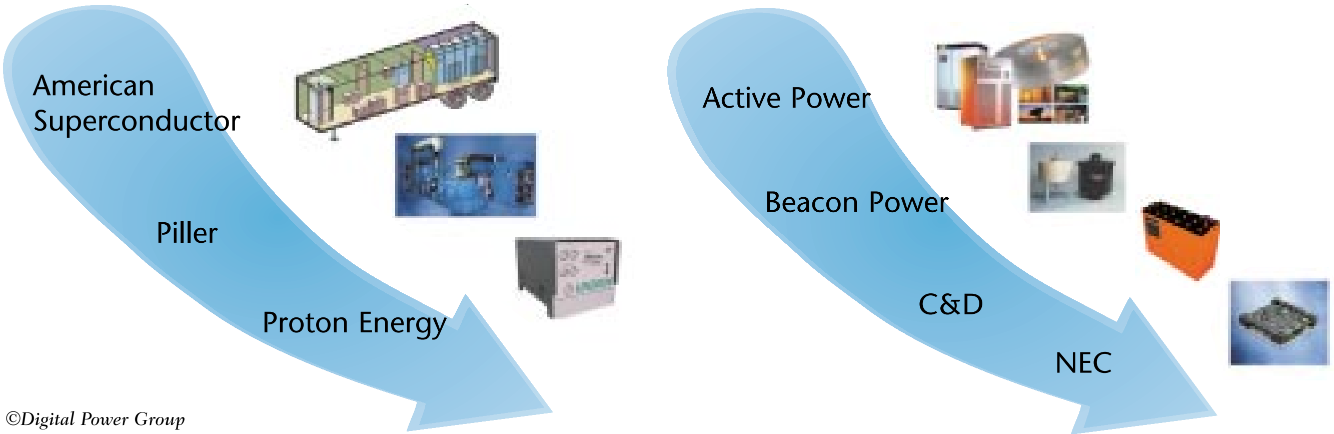
One of the most intriguing features of today’s energy debate is its over-appreciation of the importance of end-user devices and its under-appreciation of the grid. A great deal of effort and investment has focused on making refrigerators and lights and motors more efficient. But the path of least resistance to making a significant and dramatic difference in the capacity and reliability of the electric supply resides within this vast, sprawling grid of wires (***October 2000 DPR***).

Our grid was built mainly with mid-twentieth-century technologies; we now have in hand technologies that can dramatically improve both its control and its throughput. By investing heavily in substations–the “gates in the grid”–and distribution plants, one adds control. One also adds headroom. Much has been said about how the grid is stressed, and operating at the limit of its capacity. But the grid currently has to operate with a broad margin of safety, because its control systems remain primitive–just as a car has to drive more slowly when it has poor steering, suspension, and brakes. Technologies that could deliver even 5 percent more capacity in the existing wires, on the existing rights of way, would dramatically improve things, in California and neighboring states, and across the country. And changes of that order are now readily possible, with the technologies of high-power electronics and powerchips.

Digital power control systems can of course extend right down to the end of the line, and into (comparatively) low-power end-user devices–refrigerators, air conditioners, and lighting systems. Here too, they deliver–first and foremost–superior performance: performance that is faster, more responsive, and more reliable, systems that occupy less space, and that are ultimately cheaper, too.

As noted, a second tier of distributed generating systems located around the periphery of the grid can boost reliability. But to provide the high-9s power that digital

Electric-to-Electric: Electron Storage



©Digital Power Group

technologies demand, distributed generators require yet another tier of technology–storage or "ride through" systems–without which there cannot be seamless, transparent switching from grid to off-grid sources power.

Here again we find a hierarchy of devices that perform this function; from American Superconductor's megawatt-level, trailer-sized superconducting magnetic energy storage system (SMES), all the way down through Active Power's and Beacon's flywheels and Proton Energy's hydrogen storage devices to the very smallest batteries and capacitors (***August 2000 DPR***). The technology here is driven once more by the imperatives of a 24-7 economy that requires much higher levels of reliability. Demand is therefore likely to continue to grow for the foreseeable future.

Powerchips and Power Electronics. Powerchips and power electronics can be found at the center of every conversion that involves electrons, which is to say everywhere since 40 percent of all U.S. energy is converted to electricity, and then frequently re-converted multiple times. There has been a rather recent, and largely ignored, revolution in the development of silicon devices including chips and small power equipment that can handle enormous amounts of power on single wafers and on devices that are the size of your finger.

The capabilities that are now in place to switch power with microprocessor-like speeds, but with power capabilities that are a million-fold higher, portends a profound revolution in how power will be managed at all levels (***April 2000 DPR and January 2001 DPR***). Control technologies span all the major sectors discussed earlier–the automotive platform and thermal-to-motive conversions, the high-power sector and every aspect of thermal-to-electric, and the high-9s sector, centered not on power itself, but on power reliability.

Today, for example, there exists a new class of product which could be termed the "silicon power plant"–its architecture is easily recognized by most power engineers (***June 2000 DPR***). Hardware that takes power from multiple sources–from batteries, from the grid, from flywheels–and uses silicon power chips to blend them together to produce a seamless, perfect, down to the microsecond level supply of electrons through microprocessors and microprocessor-driven equipment. These are products of companies like Emerson (a firm whose roots date back to Thomas Edison), Power One, MGE, and Powerware.

In total, there are hundreds of companies involved in the business of making the interface devices, the conversion equipment for electrons that lie at the center of all progress–from low-grade fuel to high-grade power–that a modern society depends upon. Most such companies are under-recognized by analysts. All will play a critical role in advance power conversion effectiveness and efficiency, and many represent the most fecund opportunity for both investors and policy makers alike.

Two decades ago (the last period of pervasive talk of an "energy crisis"), talk of using silicon to switch megawatts in microseconds would be almost inconceivable. Semiconductor technology for power has merely lagged in its use for logic, in part because of the enormous material and engineering challenges in handling power flows millions of times greater than required for bits. Companies from the very large International Rectifier and Fairchild, to the smaller ones such as IXYS and Advanced Power, now routinely sell powerchips that are enabling radical new capabilities (and efficiencies) in everything from implantable pacemakers to refrigerators, from factory robots to grid substations (***April 2001 DPR***).

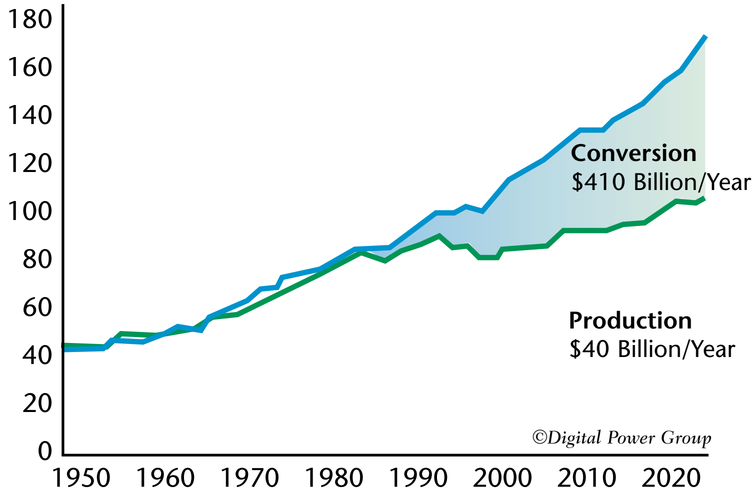
We should emphasize again that in all of these categories–from the automotive and the mass transit to the lighting sector to manufacturing–the transformation to powerchip-conversion technologies is driven, not primarily by their efficiencies, although that's an important metric, but by a desire to produce a better product. It is thus grounded in market imperatives, not political ones.

Conclusion

The vision set forth by the National Energy Policy Development Group can easily be modified to reflect investment opportunities, instead of a debate over whether production or conservation is more important (we'll need both). We still have the two curves that we examined in the beginning. One curve shows what energy growth would be if we don't improve efficiency while the other curve shows modest net growth in primary energy demand even as we do drive for more efficiency.

The bottom curve represents the production–businesses producing energy and more of it. The nation purchases about $300 billion dollars per year of raw fuels of various kinds. To keep the raw fuel flow going, we spend some $40 billion per year of capital in the technologies of energy extraction and primary production. These are vast markets, and they are growing, largely because of technological changes. The $9 trillion economy, however, is almost entirely dependant on energy that has been converted first into more useful, reliable, pure and flexible forms of power, from the electrons in the wall socket to those that make it to a Pentium, from the spinning shaft in an auto engine to the one connected to a high-tech "pick-and-place" robotic assembly motor. For all this, nearly $500 billion in capital is invested each year on power conversion technologies. Although we find both the production and conversion/conservation markets dramatically exciting in terms of the investment opportunities they offer, we find the conversion market particularly so.

Annual Spending on Energy Technology



©Digital Power Group

by Peter Huber and Mark Mills,
Co-authors, *The Huber Mills Digital Power Report*
July 2001

This report was adapted from a presentation for Banc of America Securities, May 22, 2001