THE HUBER MILLS digital power report

Special Report

The Powerchip Paradigm III

Reliably Green

by Peter Huber and Mark Mills

THE HUBER MILLS digital power report

SPECIAL REPORT

Published by Gilder Publishing, LLC

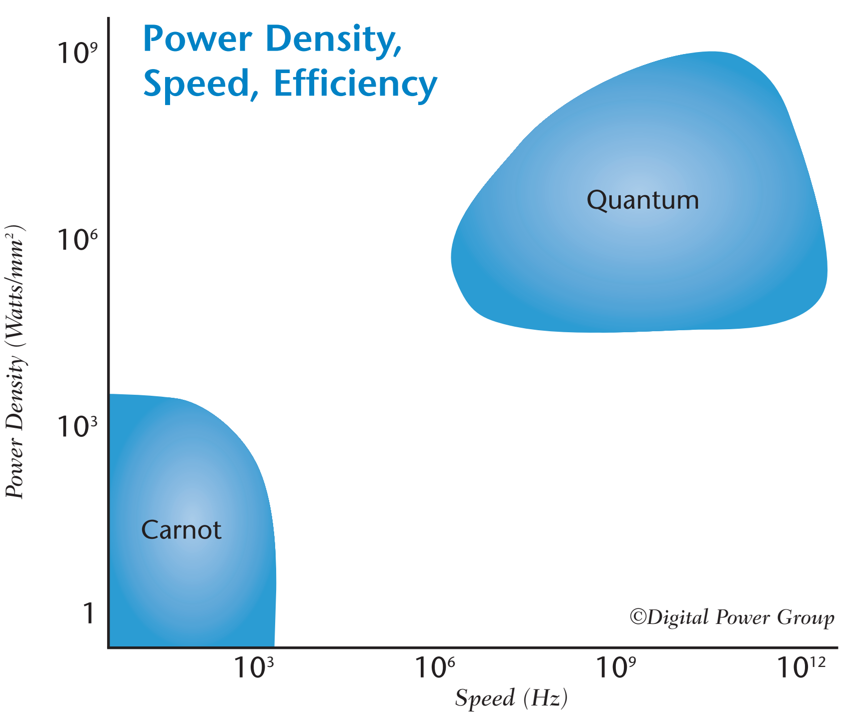
Reliably Green

Quantum technologies look as good on green metrics of "less material" and "higher efficiency"as they do on standard customer metrics of "better, faster, and cheaper."

Power is the planet's worst enemy. The fossil fuel combustion engines that provide most of our transportation and generate most of our electricity release trace pollutants into the air, combine the air's own nitrogen and oxygen to form smog, and convert carbon into atmospheric carbon dioxide that warms the whole planet. Or that, at least, is how the green establishment sees it.

Until recently, the greens hated almost all technologies favored by the power establishment. If Detroit or Duke Power liked an engine or a generator, the greens didn't. They liked renewable fuels like wind and solar, but nobody used them to supply much real-world power. The only widely adopted green technologies were add-ons, like catalytic converters and scrubbers, which were mainly grafted on to power systems to satisfy environmental regulators. Most of them added size and weight, reduced efficiency, and increased fuel consumption. To save fuel, greens pushed for additional regulation to lighten the ultimate payload: smaller cars, more efficient dishwashers, or a higher temperature setting on the air conditioner's thermostat. When power advanced the planet retreated, and vice versa.

Quantum power technologies from the semiconductor world have fundamentally changed that calculus. The transistor and its siblings transform energy not in volumes but on surfaces–atomic-scale junctions. Because they operate at these scales, they are blindingly fast and compact. On the key performance metrics of power density and raw speed, they perform vastly better.

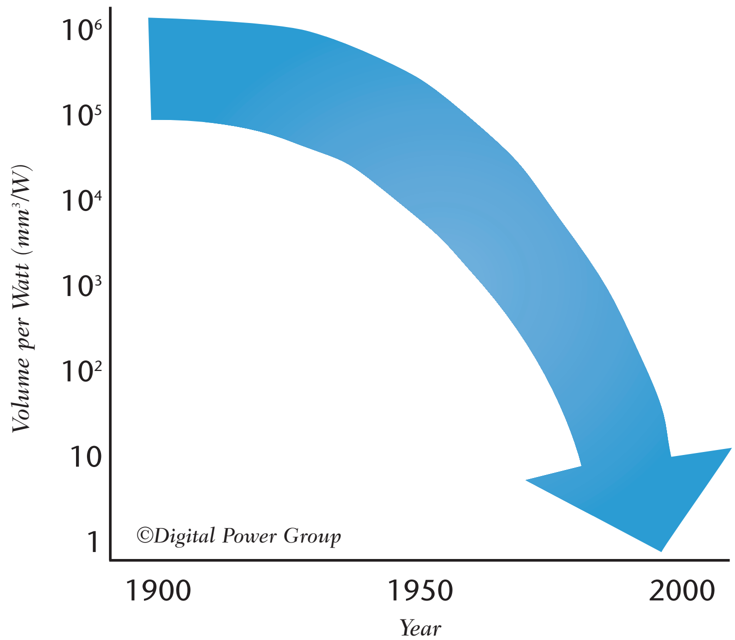


And likewise on the key green metrics of efficient use of energy and frugal use of materials. Compare today's light- and laser-emitting diodes, transistors, piezoelectric transducers, Seebeck-Peltier coolers, optical gyroscopes, and optical current and field gauges–all of which exploit quantum effects–to their traditional substitutes (like incandescent bulbs)–which don't. All are much better than Newton-Carnot systems that they replicate.

Until recently, shedding weight from a car pushed things toward the econo-box Honda Civic. With the advent of quantum technologies, it pushes things toward technologies that get deployed first in a BMW or Mercedes. The old imperatives came from fuel-economy standards and gasoline taxes–the government. The new come from the market and the pursuit of better performance–the customer. The old green answer came down to less power in less space. The new technologies make possible more power in less space. Greens won't welcome the possibility of "more," but they embrace all the rest.

Cynically or all in good faith, the producers of power can now claim to have been won over by the greens, as they install technologies they would be installing anyway to win over the most demanding customers. The selfish pursuit of better acceleration, a smoother ride, and more reliable electrons can be packaged as–and perhaps in fact becomes–the pursuit of a greener environment. Every shift to a lighter, smaller system can be portrayed as–and perhaps is–the fulfillment of a civic duty, even as it generates a higher profit. Quantum technologies look as good on standard green metrics of "less material" and "higher efficiency" as they do on standard customer and bookkeeper metrics of "better, faster, and cheaper." Less clear is whether they will also deliver less total consumption of energy, as many green advocates hope and predict. For now, it suffices that many greens themselves are convinced that they will.

Shrinking Power Footprint



The footprint of power technologies keeps shrinking, now accelerated by a vast new class of quantum devices.

Distributed Generation

Most greens are distributed generation (DG) enthusiasts. Heavily digital businesses are too, and even more so. To the greens, DG leads inevitably to solar and wind, to warm the hot tub without the grid. For digital enterprises, DG means backup power to keep the silicon hot when the grid's power fails. But both camps are spending most of their money on much the same technology–mainly switches and storage systems, not fuel.

For 24x7 power, solar cells and windmills must be linked to banks of batteries, or a big flywheel, or some other storage technology, along with transformers, rectifiers, inverters, and switches to shuffle power among the various devices that generate, store, and consume it. Backup power systems require the same hardware, for the same reason–the grid itself doesn't deliver perfect 24x7 power, either, and it takes the same array of storage and control to get beyond the grid's imperfections. Either way, you build a short-wire grid that provides power when the long-wire grid doesn't.

The greens' fondest hope is that the short wire will end up leading to a photovoltaic cell, or a windmill, or an on-premises fuel cell. If it's a fuel cell, it will provide hot water and space heat too, for terrific efficiency overall. But in the configuration already used by millions of businesses, the short wire in fact leads to a bank of batteries–which get recharged by the grid itself.

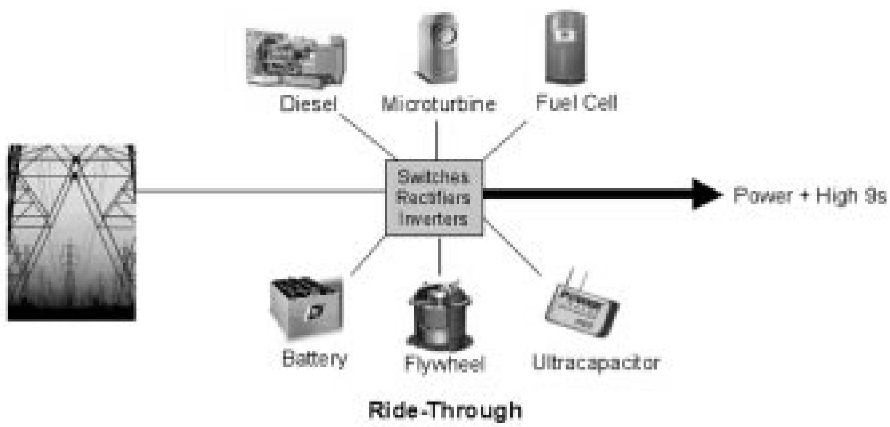
The green case for DG often rests on a waste-recycling model for energy. Until we get to solar or wind, short-wire technology lets us squeeze some extra value out of the waste heat from fossil fuels. But demand for more reliable power has proved much stronger than demand for recycled heat. Waste heat has sold only slightly better, all in all, than recycled newspapers and aluminum cans. The market for reliability, by contrast, is now growing explosively. Chaos–waste heat–is very much less interesting, it turns out, than high-9s order. But vendors of short-wire technology will happily sell you either, or both.

Because they have to run right in your face, short-wire technologies have to be very clean. One traditional response to air-quality regulation has been to site plants further from urban areas, and build taller smoke stacks–the dilution fix for pollution. Short-wire power plants, by contrast, give new, personal meaning to the "polluter pays" principle. Self-interest can easily eclipse regulation as the main reason to keep things tidy. Fuel cells were first developed for space capsules, where compact, clean, cool, and quiet mattered a lot on the inside, however little anyone cared about environmental quality outside.

Back on earth, companies like Capstone (microturbines) and FuelCell Energy can locate generators where diesels can't go–close in to techie cubicles, gigahertz server racks, and wireless base stations. Gas-fired aeroderivative turbines can likewise be located at urban substations where other combustion generators would be unacceptable. Once again, the immediate consumer's interests come into line with broader green objectives.

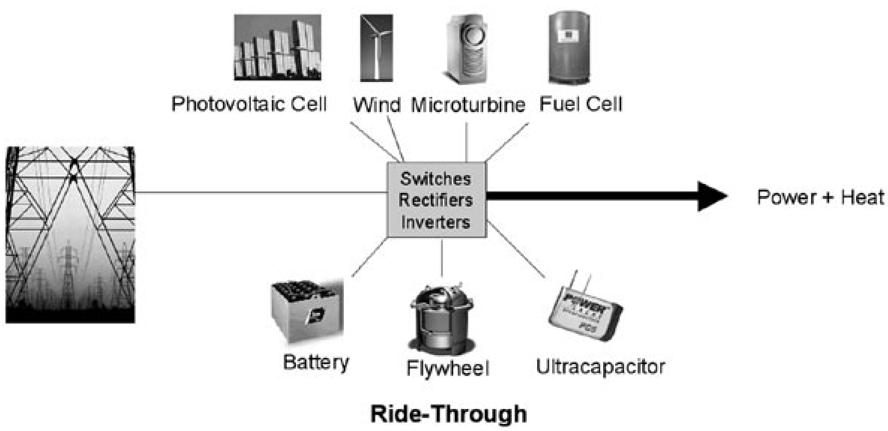
Wherever regulators will let them, the old-guard electric utilities are rebuilding their grids in much the same way as their high-end customers are rebuilding

High 9s Architecture



©Digital Power Group

Green Architecture



©Digital Power Group

things at their end of the power line. And even in the much-despised grid itself, much of the action now centers on technologies that greens should like.

The utilities are adding and rebuilding substations–the grid's own "gates," where its intelligence resides. High-power quantum technologies make possible faster, smaller, smarter switches even at these very high-power nodes. Better gates significantly boost the grid's efficiency, much as they can boost a refrigerator's or a washing machine's. Almost all the gains come at brown-field urban sites, which end up smaller and cleaner after the changes are made. And by shrinking existing components, the architects of the new substations are making room for thousands of new ultra-low-emission 15-60 MW gas-fired turbines, and perhaps, eventually, for molten carbonate fuel cells. Superconducting cables are coming next; they use much less material, and much less space under the streets, and replace oil with nitrogen as coolant for the wires.

The Silicon Car

Until recently, most of the "electric car" hype centered on such things as fuel cells, or batteries, to replace the primary power plant. The combustion engine itself may never be overtaken by electric technologies, but it is now clear that all the rest of the power train surely will be.

As we have written elsewhere, the convergence of digital logic and quantum power technologies is now fundamentally changing how we build things to move things. The old, painstakingly complex arrays of click-click bang-bang belts, pulleys, gears, valves, rocker arms, and pulsing fluids are now rapidly giving way to all-electric power trains.

Direct-drive digital systems are smaller and lighter because electrical power requires much less transmission hardware than mechanical or fluidic alternatives. As a power-transmitting technology, an electrical wire can be far more robust, and far more tolerant of hostile environments, and much less in need of periodic maintenance, than a shaft, belt, pulley, or fluid-filled pipe. This is an advantage even on a stationary assembly line, and a very substantial one when it shaves hundreds of pounds off the weight of a car or plane.

A dramatic slimming down is now under way in mechanical systems across the landscape. What happened to the mechanical wristwatch and the electromechanical telephone switch is now happening in much larger mechanical systems, including, most notably, those found under the hood of the car. The internal combustion engine stays, at least for now, but stays to spin a generator. The (low-9s) electric power is converted and switched by an array of silicon powerchips. A "ride-through" storage system–typically batteries, increasingly combined with ultracapacitors–is needed to accommodate the highly variable loads of stop-and-go traffic. And wires convey the power to precision electrical devices at the end of the line. The architecture of the power train in tomorrow's car ends up a mirror image of tomorrow's grid. The car is different only in that it presents an exceptionally wide chasm between low quality power delivered to the car's "grid" at one end, and the highly variable demand for precisely modulated power at the other.

These technologies are now being rolled out commercially, and at the top end of the market, because they deliver much better performance. Within two decades, they will have replaced hundreds of pounds of click-click bang-bang mechanical, hydraulic, and pneumatic hardware under the hood of almost every car and truck. The powerchips are working with the market, not against it. They deliver what ordinary drivers want–better performance, more safety, and lower cost.

Happily, they deliver what green advocates want, too. All-electric steering alone boosts fuel efficiency 1 to 3 percent–by reducing weight and more importantly by drawing power from the engine only when needed, rather than continuously as occurs with mechanical power-steering systems today. An integrated starter/alternator is lighter and smaller too, and it can use the battery to boost torque intermittently, which means more power from less engine, which boosts efficiency by another 20 percent or more. Electrically actuated engine valves offer astounding 10-40 percent gains in efficiency, and even larger reductions in emissions. Even all-electric suspension has an efficiency pay-off–less gas from the tank ends up heating the oil in the Monroe shock absorbers.

The improvements compound with each additional smart "client" added to the car-wide Web. Torque, traction, braking, skid control, fuel economy, and emissions all depend on the complex interaction of engine, battery, suspension, steering, and brakes; the magic lies in the intelligent coordination of all the parts. Emissions depend on exactly the same interactions; the intelligence that is added to improve performance along every other dimension can readily improve performance along green metrics too. A combustion engine generally runs cleanest when it runs very steady. But it doesn't, not in stop-and-go traffic–until it's enlisted to charge a battery or a bank of ultracapacitors, rather than to drive the wheels directly. Storage technologies favor slow and steady as much as the greens do.

The greens again hope that the end of the process will be a fundamental change in the prime mover itself. With the grid they pin their hopes on sun and wind; with the cars, their current hopes are centered mainly on fuel cells. They support the siliconization of the rest of the car in part because they know a fuel cell requires an electric power train, just as solar and wind power require a short-wire infrastructure. Perhaps things will get there in the end. Perhaps not. The manufacturers of combustion engines keep improving their products, too. But whether the internal combustion engine itself lives or ultimately dies is almost beside the point. Most of the opportunity, and most of the spending, lies in the power train, not in the engine itself. And performance objectives are now pushing all of that in exactly the direction that green advocates say they favor.

Light

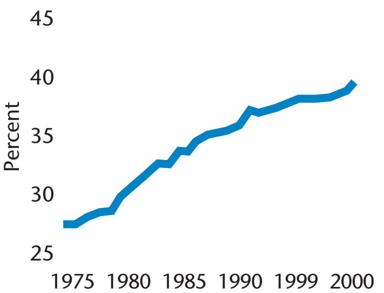
The twenty-dollar fluorescent light bulb was once the poster child of green high-tech. Regulators directed utilities to buy them for your house. The logic of "Negawatts" was that regulators could invest capital more productively in bulbs than utilities could invest it in turbines. The bulbs performed just as promised: they delivered more light from less electricity. But poor-quality light, unfortunately. From an ugly bulb that was much too big to fit into most sockets. And that cost twenty times more up front. Businesses bought fluorescent lights where they made sense for enterprises that had full-time facilities managers. But few residential users would touch them.

Invented in 1962, light-emitting diodes (LEDs) now offer something altogether different, and very much better. The new bulbs aren't bigger, they're smaller–they shrink the "bulb" from the size of a pear to the size of a poppy seed. Per unit of area and of energy used, semiconductor "bulbs" are far brighter than Edison's, which means they can be far more compact, efficient, and cool. They are so much better, in fact, that it is now reasonable to project that solid-state light will almost completely supersede Edison's filaments within the next few decades. Electron-to-photon transitions can now be accomplished much more compactly and efficiently at quantum junctions than in heated filaments or excited gas cavities.

The transition has already occurred wherever it is important to supply more light with less power. In battery-powered devices of every description, from wristwatches to emergency exit signs, to traffic lights. In cars, from the dashboard to the taillights, and soon the headlamps too. Full-color LED displays are possible now that the blues have joined the more common reds and greens. Baseball parks are now erecting huge ones for instant replays. Some 18 million LEDs light the NASDAQ's huge display in New York's Times Square. In most of these applications, better, cheaper light accounts for more of the burgeoning demand for LEDs than lower power.

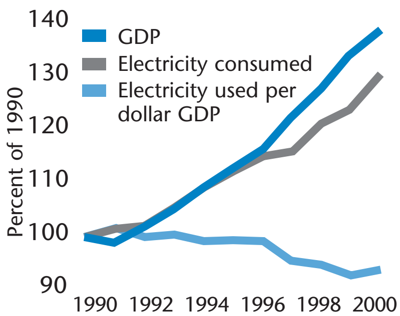
The LED performs far better on standard green metrics, too. Silicon carbide LEDs have reached a stunning 28 percent electron-to-photon conversion efficiency. Incandescent bulbs, by contrast, typically run at single-digit efficiencies. The entire output of an LED can be aimed in a single direction. And the LED requires less material to build, and is lighter, which translates into further savings on all mobile applications like cars.

Share of U.S. Energy Consumption for Electricity



Source: Energy Information Administration

GDP and Electricity



Source: Energy Information Administration

The laser diode takes light one major step further. In terms of coherence, and thus power density, and thus overall energetic order, the laser is millions of times better than Edison's bulb. It punches more power through less space–power densities of 20 MW/cm^2 are now routine. Only in a high-voltage power line do power densities routinely run any higher (100 MW/cm^2). In everyday applications, laser light is the pinnacle of highly ordered power.

Lasers aren't displacing old forms of light–they're displacing old forms of heat, and old uses of electricity. Photons are displacing electrons in datacom and telecom applications, of course. Nothing can read bits (from a CD, say) or transmit them (through fiber optic glass) faster than a laser. But lasers are also moving rapidly in on the moving of atoms and the processing of materials. Lasers move ink in printers and etch silicon and metal. As "nanowave ovens" they solder opto-electronic chips, and burn hair, cauterize tissue, and reshape the surface of the eye. They supply unequaled precision in the bulk processing of work-a-day materials–heat-treating, welding, polymer bonding, sintering, soldering, epoxy curing, and in the hardening, abrading, and milling of surfaces.

And again, lasers outperform conventional alternatives on the standard green metrics, too. A fiber-optic system requires far less power to transmit bits than an electric wire. The nanowave oven can be aimed and focused with unequaled precision, which means that it illuminates or moves or heats more payload and less extraneous real estate. Microwaves can heat just the water in the soup, not all the air and stovetop around it; lasers do the same, only more so. If microwave ovens are greener than conventional ones, nanowave ovens are greener still.

Less Energy?

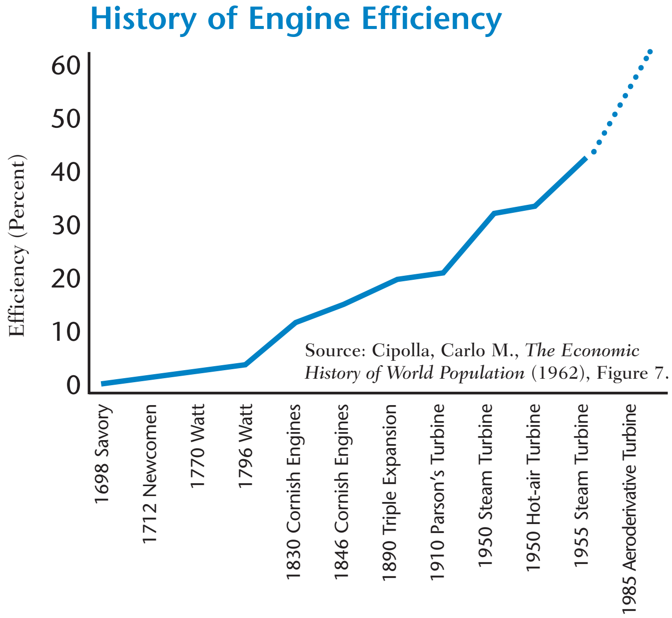
Greens often point out that energy consumption *per unit of GDP*, has been falling steadily. They're right–but it has been falling for 20,000 years. The GDP of the subsistence farmer is nothing but energy–food calories. Wealthier economies add less energy-intensive goods to the mix, so energy per GDP invariably falls. It just doesn't take much oil to make software, or to run a symphony orchestra. The "dematerialization" of the economy is real enough, but entirely relative. Our consumption of knowledge-intensive goods is growing faster than our consumption of energy-intensive ones. But both continue to grow.

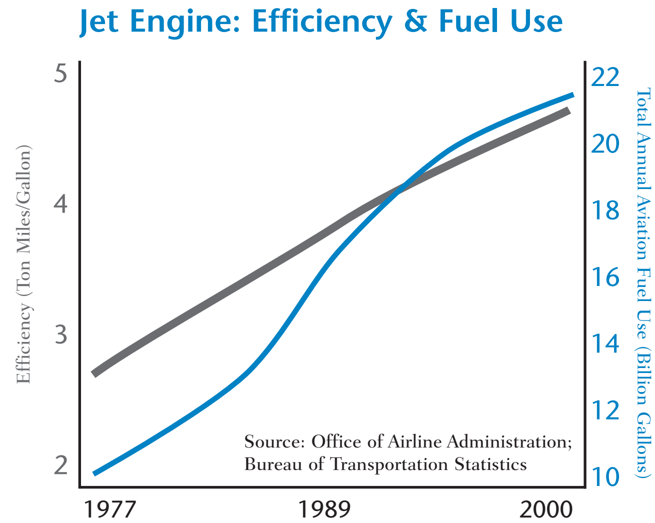
The great green hope is that GDP growth can be decoupled from energy consumption entirely–that gains in efficiency can first stabilize, and then roll back, our total consumption of energy. And why not? All other things equal, a lighter, more compact, more efficient motor, engine, or light bulb requires less power than the alternative. Perfect on-the-fly tuning of a motor delivers better acceleration, and it also delivers better fuel economy and lower emissions. Digital technologies consume some power in their own right, of course, but their "bit efficiency" doubles every year or two.

Efficiency is indeed rising across the board. But whether that translates into less total energy consumption is much less clear. It hasn't so far. Within the chip itself, the electrical energy required to process a single instruction is cut in half about every eighteen months. But the number of gates per chip, the chip's clock speed, and the total number of chips rise too. Overall, the number of bits processed rises much faster than bit-efficiencies improve. Per-bit processed, a DVD is much more energy efficient than a vinyl record. But nobody used to give a personal movie theater to fractious kids in the back seat of the car. Per-bit conveyed, lasers and fiber-optic glass are stupendously efficient compared to the electrical wires they displaced. But the old wires didn't route terabytes of data. The ENIAC computer of 1946 was an enormous beast, with 18,000 vacuum tubes that consumed 180,000 watts of electrical power. A 5-watt Nintendo 64 offers 3,000 times as much computing power today. But one Nintendo per teenager adds up to a whole lot more electricity than one ENIAC per planet.

The new digital infrastructure runs 24x7, and the always-on duty cycle eclipses almost everything else in its impact on the electric meter. Though widely touted as a substitute for the grid, the distributed power systems now being deployed actually consume large amounts of grid power. The cheapest, most reliable, most hassle-free substitute for grid power at 4:00 p.m. is grid power delivered to a lead-acid battery or flywheel twelve hours earlier. But using the grid to charge up the battery in a UPS is a step back, environmentally speaking, because the charge/discharge cycle is very inefficient.

What some green futurists hope for eventually is a tight integration of the hybrid electric car's grid with the





home's, around high-efficiency, thermo-electric fuel cells. What's more likely to come however, is the hybrid electric car–an efficient (and clean) way to deliver miles, but an inefficient (and dirty) way to run a dishwasher. Even allowing for the (quite modest) losses over long transmission lines, big, centralized steam turbines generate electricity far more efficiently than any small gasoline engine ever can.

That consumption tends to rise as engineering efficiency rises is less of paradox than it may seem at first blush. Raising the efficiency of an engine or motor has much the same effect, it turns out, as lowering taxes on its fuel. Lower the engine's own hidden tax on energy without simultaneously raising the government's, and total energy consumption will generally rise, not fall. The great green hope is that efficiency can somehow be pushed over the cusp of the curve, to the point where more efficiency translates into less consumption. But all the real-world experience so far indicates that we're nowhere near the point where we turn that corner.

This is as true today as it was in 1962, when the great economic historian Carlo Cipolla summarized the story up to that point, in *The Economic History of World Population*. "Remarkable improvements" had been made in thermal engine performance, he noted, raising efficiencies from an average of 9 percent in 1920 to an average of 24 per cent in 1942. As a result, "the U.S. could produce in 1955 the same quantity of goods and services with 35 per cent less energy than in 1920." "But there is still a long way to go." In the four decades since, the efficiencies of almost every major power technology used in our economy has approximately doubled. But total energy consumption has nearly tripled too.

Perhaps we will eventually discover, as some greens predict, that by consuming more power in chips and fiber-optic lines, we will consume less energy elsewhere. The Web makes possible telecommuting and on-line shopping, which substitute–some greens believe–for energy-intensive car trips, shopping malls, and warehouses. But then, bits were also expected to reduce the use of paper in the office; so far, at least, they seem to have had the opposite effect. When ordered on-line, Harry Potter often travels by overnight air. On-line is certainly convenient, as is overnight door-to-door delivery of an individually packaged book. But greener? Much as we'd like to believe it, we'll leave the defense of that proposition to others.

And even if the bits-for-atoms displacement does eventually happen, the consumption of electricity, and its share of our overall energy budget, will grow all the faster. Electrons are the power of the microcosm, the power of the telecosm, the power of the digital age.

Peter Huber and Mark Mills
July 2001

The Digital Power Report is published monthly by Gilder Publishing, LLC. Editorial and Business address: 291A Main Street, Great Barrington, MA 01230. 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