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Heavy-Iron Lite

General Electric is uniquely positioned to squeeze digital quality power from powerchips, fuel cells, superconducting coils, and turbines

So what about the heavy-iron? The 15 to 250 MW turbines? In the Powercosm, or out? In. Some, at least. Leave it to the Economist, the Worldwatch Institute, the small-is-beautiful crowd, to tell you that micropower rules, that big power is finished, that utility-scale heavy iron has as much future as a thirty-year-old IBM 360. Micropower is going to prosper. Macropower is going to prosper too.

General Electric (GE) is the IBM of big electrons. Overall, GE turbines account for an estimated 30 percent of current U.S. electric capacity, and some 60 to 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 equipment 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 to 60 MW range.

Call it heavy-iron lite. Demand for GE's fully packaged aeroderivative 23 to 60 MW gas turbines increased more than 200 percent in the second quarter of this year; shipments increased 122 percent. U.S. orders now stretch beyond 2003, with customer commitments of $23 billion, including $11 billion in long term service agreements. GE has also seen a recent 80 percent surge this year in U.S. orders for its high-end, ultra-heavy, central station gas turbines. But the heavy-lite turbine will utterly dominate North American markets for large scale generating capacity in the next decade, in terms of both dollars spent and megawatts of new capacity ordered.

OK, (highly lucrative) GE Capital is a $50 billion-a-year distraction. So is GE's television network (NBC). But there's still a healthy chunk of "electric" in the $112 billion company—turbines, electric transformers, switchgear, meters, controls, appliances and, of course, lighting. Much of it is still anchored in the twentieth-century electron technology, but 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. GE is about to acquire a new CEO. Memo to new management: thank Jack for getting the company into banking a decade ago. It was a brilliant move when electrons were in the doldrums. Now get over it. Lose the bank. Lose the television network. Run with the electrons. Roll up the Powercosm.

But suppose passionate greens end up running the country? They hate heavy-iron, right? Right. And the internal combustion engine, too. That didn't deter them from opening the spigot on the nation's emergency oil reserves when prices at the pump began to rise. Voters won't stand for a chronic electron crisis either. Clean air will indeed remain a high priority, regardless of who's minding the store. Enter Catalytica (Mountain View, CA, currently CTAL, but soon to be CATX). When it comes to squaring megawatt-scale gas turbines with clean air, Catalytica has the solution in its revolutionary Xonon technology.

More Electrons

The epicenter of energy markets has shifted from Abu Dhabi and the oil beneath the sand, to San Jose and silicon made from sand. The price of kilowatt-hour now matters more than the price of a barrel of crude.

Demand for electric horsepower under the PC's hood doubles every couple of years. Each new generation of CPUs processes more bits per Watt. The electrical energy required to process a single logic instruction —

now about 10^{-5} picojoules — is cut in half about every 14 months — down about twelve orders of magnitude since 1940. But the number of logic operations, gates per chip, and cycles per chip (clock speed) — and thus, total bits processed – has risen much faster. Bottom line: the amount of power consumed by the Intel (INTC) CPU has doubled about every 36 months. (See http://www.electronics-cooling.com/html/2000_jan_a2.html). And the chips themselves are, of course, multiplying like locusts.

The faster the chip, the more exacting its demands for power. For a 1 GHz chip, a "blackout" is an interruption that lasts one billionth of a second on the silicon surface. The Powercosm is what is now rising up to meet such exigent demands for power reliability. And adding reliability requires still more power.

Take the standard desktop UPS, car-like battery plus electronics, powered by the grid. UPS efficiencies typically run about 80 to 90 percent – 1.2 Watts in from the mains for every 1 "uninterruptible" Watt out to the PC. Same with an Active Power (ACPW) flywheel (August DPR), an American Superconductor (AMSC) SMES (October DPR), or with hydrogen generated by reversing a fuel cell from Proton Energy Systems [(PRTN) September DPR]. It takes a lot of power just to layer and switch between multiple sources of power – power to keep the MOSFET and IGBT powerchips hot. In short, it takes electrons to make electrons themselves more reliable — every extra layer of reliability infrastructure entails some vigorish for the house. And the vigorish entails still more vigorish. All the energy that enters a building as electricity must leave it again through an air conditioner – and that typically boosts power loads another 40 percent.

For a long stretch – one that ended only in the last 12 months or so — no-growth pundits persuaded regulators, and through them hapless utilities, that there would be little or no further growth in demand for wholesale electrons. By 1995 new capacity orders had dropped to a level of about 10,000 MW a year, where they remained until 1999. Today, demand is growing at 20,000 to 30,000 MW per year. The non-transportation sector of our GDP (about 90 percent of the whole) already gets over half its energy from electricity. Over 80 percent of all growth in U.S. energy is now supplied by kilowatt-hours. Total electric demand is growing at least 2.5 percent a year – and recent numbers are pushing into the 3 to 4 percent range. These may sound like tiny percentages for anyone accustomed to what counts as "rapid growth" in the Telecosm. But they are small only because Thomas Edison had a century's lead over Andy Grove, small because the world of power is so huge to begin with.

Distributed Generation

So where will the new supply come from? Some from improving the grid (see this month's companion issue). Grid losses (5 to 7 percent) can be lowered further still. And the grid's capacity to deliver power over greater distances can be boosted, permitting utilities to better match capacity with demand. In theory, a Tokyo power plant idled at midnight could power New York's air conditioners at noon, and vice versa. But in practice, grid improvements must give way to more generating capacity, sooner or later – mostly sooner, these days.

What kind of capacity? The traditional coal-fired plant looms on the horizon at 500 MW, and takes years to build. So when demand for power is rising unexpectedly fast, as it is today, suppliers and operators of really heavy-iron often can't respond fast enough. Smaller units can be rolled out a lot faster. That fact alone accounts for much of the current enthusiasm for distributed generation (DG).

We like DG too, but what we like about it is the short wire and the reliability gains that can come with it. A 250 MW turbine requires a sprawling grid, which inevitably degrades reliability. Shorter wires are more secure. Thus, for larger, mission-critical users, for Powercosm hotels, the AOLs (AOL) and the EMCs (EMC), the transition from low-9s to high-9s invariably means the addition of on-premises sources of backup power.

There is now at least 80,000 MW of DG capacity in place in the United States — compared with 780,000 MW of central station capacity. No less than 1 MW of new DG capacity is now being ordered for every 2 MW of heavy iron, and the former is being installed much faster. The fastest-to-market heavy-iron, heavy gas turbines, are typically at least three years from order to installation, while the light DG, a year or less. (Many of the heavies are speculative orders too, placed by merchant plant "place holders" still without permits or construction under way.) The actual install rate of DG to heavy MWs now approaches 1 to 1 – with over 15,000 MW going in this year. And the largest amount of DG capacity by far, and fastest growth (up 100 percent this year) is in the heavy-lite sweet spot (15 to 60 MW). The center of gravity is decidedly shifting from heavy to heavy-lite, and we expect it will accelerate.

Still, for now, Caterpillar (CAT) with diesel gen-sets under 2 MW, ranks among the top suppliers of electric generating capacity, with 165,000 MWs (diesels) installed

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worldwide at year-end 1999. AOL has a baker's dozen 2 MW Cats outside two of its major centers in Prince William County and Herndon, Virginia. Real estate companies and silicon hotels like Exodus (EXDS), Equinix (EQIX), Intel Online, Level3 (LVLT), and Qwest (Q) have become major owner-operators of DG power systems. In the next 18 months, the build-out of Powercosm hotels alone will require at least 20,000 MW of additional DG back-up. But for their class of loads, for both on-premises and nearby utility substations, heavy-lites will begin their domination.

All of which sounds like bad news for the heavy-iron power producers. Most DG capacity sits idle most of the time, but it doesn't have to. Once in place for the last six 9s, nothing much stops DG from generating some, or all, of the front-end power too. Sooner or later, fully-insured, turnkey 9s service companies will use "excess" DG capacity to avoid, or even re-supply, the grid, taking full advantage of pricing absurdities and inflexibilities that the regulatory system imposes on utilities. Environmental regulators often favor DG too. They like to promote and subsidize technologies they deem to be especially green, which generally means almost anything but the heaviest iron.

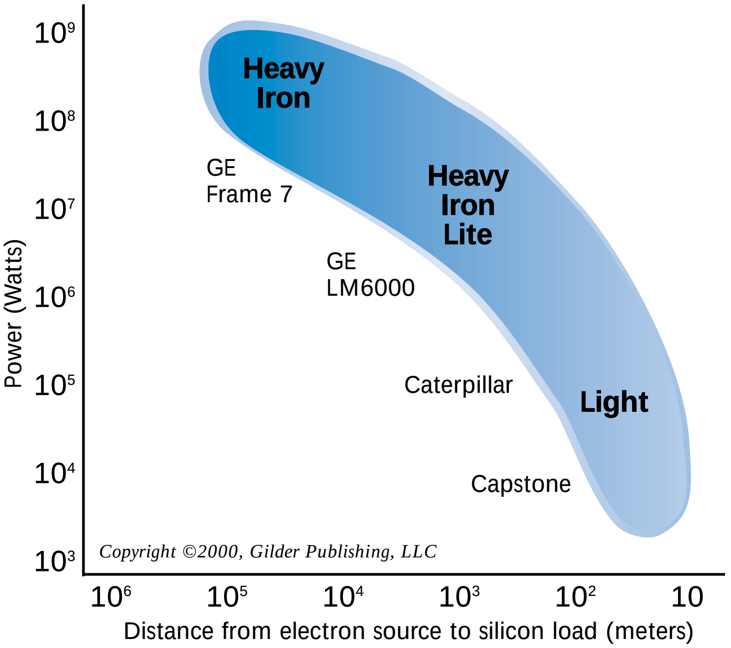
The Law of the Macrocosm

But not so fast. The supply of wholesale power isn't governed by Moore's law, it's governed by Carnot's. (Sadie Carnot is the thermodynamics guy). Bigger systems, not smaller ones, have a crushing advantage when it comes to moving bulk electrons. Today's supercomputer is indeed assembled out of thousands of Pentium microprocessors. But a utility central power plant sure isn't a massively parallel array of 30 kW Capstone microturbines, it's four 256 MW GE MS9001FA behemoths. The reasons lie deep in the basic engineering. And the laws of the macrocosm are not about to be repealed.

In the Carnot world – in thermal systems — bigger is almost always more efficient. A 180 MW GE Frame 7 central station turbine pushes 58 percent thermal efficiency; Capstone's 30 kW microturbine hits about 26 percent. A utility running the GE turbine has a capital cost of $200/kW, and can churn out 3¢/kWh electrons; a Capstone unit runs about $1,000/kW and 15 ¢/kWh.

And the heavy-iron isn't about to lose its efficiency edge. Even as oil prices have gyrated, the average retail price of the kilowatt-hour has fallen 10 percent since 1990, and wholesale prices are in virtual free-fall. Yes, California and a few other states saw wild swings in their electricity rates recently. But these were direct consequences of regulatory ineptitude –decades of suppressing supply, followed by an abrupt deregulation of price. Virtually all of the micropower technologies in actual use – diesel generators and small turbines are, and will remain, much less efficient, and therefore much more expensive. This is why the unreliable grid was built in the first place. The engineers weren't stupid. They understood that by aggregating loads they could lower price. Viewed from that perspective, the K-9 grid isn't a dog at all, it's a triumph of efficiency.

Megawatts and Meters in the Powercosm



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Combined-cycle gas turbines in the 15 to 60 MW range now define the sweet spot for heavy-iron. Call it heavy-iron lite–big enough to be efficient, compact, cheap and clean, but small enough to be deployed quickly, and to be dispersed throughout the grid, closer to loads.

Efficient when it comes to rolling out the hardware and deploying it on real estate, too. Ake Almgren's Capstone can't churn out 1,000,000 units next year, which is what it would take to meet the demand growth. Exodus, Global Centers, Sun (SUNW) and Oracle (ORCL) now have 20 to 100 MW loads. Back up those corporate campuses with 1 MW truck-mounted CAT diesels, and the parking lot will look like a truck stop on the New Jersey turnpike. And perhaps smell like one, too. With the right emissions control equipment, the heavy iron can invariably run cleaner, watt for watt, than the light. Serious green regulators know that.

So heavy-and light-iron can indeed compete at the margin, but in practice the margin is pretty thin. Mostly, they're complements, not substitutes, with the DG layers added mainly to cut in when the grid goes down, not to displace grid electrons when the grid is up. The heavy iron can't compete against DG on the last three 9s; DG can't compete against heavy-iron on the first three. Thus, the manufacturers of heavy-iron are going to supply the first three for a long time to an economy whose overall appetite for electrons is rising inexorably.

The 180 MW Boeing

Twenty years ago, the only really efficient turbines were huge, 100 to 250 MW and up, with several operating in parallel in the gigawatt-scale power station. Turbines of that size – manufactured by GE, Siemens-Westinghouse, Alstom [(ALS) France], Mitsubishi Heavy Industries (MHI), and Ensaldo Energia (Italy) — still generate most of our wholesale electrons. These turbines operate on pure steam, supplied from external boilers and heated by external furnaces, that are fired by natural gas, coal, uranium, or oil. They typically reach at least 40 percent thermal efficiency. The most modern steam units are pushing 50 percent (approaching the efficiency of big gas turbines), putting them quite near the outer limits established by the second law of thermodynamics.

> ***Next time you board a 747, take a look at the GE CF6 class engines under the wings–count on seeing their cousins next in hundreds, perhaps thousands, of locations across the country***

It was the rise of the jumbo jet that led to the creation of a new, efficient space in the middle. The airlines began demanding much more efficient turbines to bolt under their planes' wings. Led by GE, jet-engine manufacturers pushed the technology relentlessly forward. A remarkable stealth revolution in materials science made it possible to push gas turbine intake temperatures up to 1,100°C, and then to 1,300° C, and efficiencies rose apace.

As jet engine technology improved, it became clear that with only minor modifications, "aeroderivative" turbines could be bolted to trailers as well as under wings, and used to spin a generator rather than the air-fan in a jet. Because weight matters less, and efficiency even more, the "simple cycle" (35 to 40 percent efficient) jet engines were converted, in the 1980s, to "combined-cycle" systems, in which hot exhaust from the gas turbine is fed to a steam generator alongside, and the steam is fed in turn through a second turbine. In combined cycle operations, efficiencies pushed up to 43 percent and then (in 1995) to 48 percent. In combined-cycle operations, aeroderivatives now achieve 52 percent thermal efficiency. That's somewhat lower than the essentially at-the-limit 58 percent achievable with the biggest (plain old heavy) "frame" turbines in combined cycle operation, but it's high enough. Taking into account capital, time-to-market, and fuel costs, the most economical generating plant now runs in the 10s of megawatts, down from 100s of megawatts in the 1980s.

So the next time you board a Boeing 747 (a 180 MW four-engine machine), take a good look at one of the GE CF6 engines under the wings. Count on seeing their cousins next in hundreds, perhaps thousands, of locations across the country — 22 MW or 43 MW engines on a trailer, from the newly launched GE Energy Rentals division. Combined-cycle gas turbines in the 15 to 60 MW range now define the sweet spot for heavy-iron. Call it heavy-iron lite — big enough to be efficient, compact, cheap, and clean – but small enough to be deployed quickly, and to be dispersed throughout the grid, closer to the loads. Orders for heavy turbines still dominate total capacity additions — 35,000 MW of orders for heavy-iron units over 120 MW this year (but no change, though, over the already hyberbolic 1999 order level). The second largest, and fastest growing, category is now the 15 to 60 MW heavy-lites, with nearly 8,000 MW of orders this year, ten times the 1999 order level – and due to be installed in short order (unlike the heavies).

The heavy-lite turbines are especially attractive to upstart "independent" power producers, like Calpine c*Power (a wholly owned subsidiary of Calpine Corporation [CPN] San Jose, CA), Enron [(ENE) Houston, TX] and Alliance Power (Denver, CO). They are the power industry's equivalent of just-in-time inventory — they can be delivered in a matter of months, or faster still when mounted on barges. Last summer, PG&E was preparing to float a 95 MW barge (three Pratt & Whitney turbines) from Houston, through the Panama Canal, and into the San Francisco Bay, to a site near San Francisco International Airport. Environmentalists managed to block that plan. But 74 turbines, totaling 2,000 MW — ugly, unpopular, and essential — are already afloat on power barges around Manhattan.

The heavy-lite units are used primarily for peaking. They are easy to turn on and off – start-time is under ten minutes, compared to tens of hours to fire up or cool down the super-heavy iron. In combined-cycle systems with multiple gas turbines, they can be powered up (or down) unit by unit, to track the loads. And real estate is now opening up to accommodate them. As described in the October companion issue, components that have occupied a lot of substation real estate in the past are now being replaced by new technology with a smaller footprint. Shrink in half the footprint of the gear in an existing 100-MW substation, and you free up enough space for a brace of LM2500s. The substation is "sub" no longer – it's now a full-fledged "mini-station" – or what has been called a "UPS Substation."

With heavy-lite capacity in place, the utility can form an island of higher-9s power around it. The utility's own power can now sit on the doorstep of the large, high-9s customer. Frequently, the DG mini-station is sited in urban centers where the power lines are relatively short, and buried, and that adds 9s too. Even if the generators aren't right on the customers' premises, mini-stations let the utility compete for the middle three 9s now required by countless smaller businesses. And even if located somewhat higher up the grid, the mini-station stabilizes the grid by spreading capacity around, and allowing faster startup of generating capacity to meet rising demand.

General Electric

So whose turbines? General Electric's. Overall, some 6,300 GE-designed gas turbines are now installed or on order worldwide. There are going to be a lot more.

In the 1990's, GE (along with CFM International, a company GE owns jointly with France's Snecma) secured more than half of global commercial jet engine orders. GE now leases thrust-hours, putting all the hardware, maintenance, and repairs — everything but the fuel — in a single turnkey service contract. Simple, high 9s thrust in the highest-9s transportation environment — and a powerful portent of what is now emerging in the silicon Powercosm.

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. Ranging from 14 to 43 MW, GE's aeroderivative LM turbines now dominate the heavy-lite market in North America, with an estimated 60 percent share. GE's new Energy Rentals division will deliver a four-trailer 22 MW "power-plant-on-wheels," typically within three days.

GE's biggest heavy-lite sellers: the LM2500 (derived from the aero CF6-6, on the ground as a 22 MW 37 percent efficient unit in simple cycle, pushing 50 percent in combined-cycle) and the LM6000 (parented by the aero CF6-80C2, earthbound as 43 MW at 42 percent efficiency, reaching 52 percent in combined-cycle). The former was originally developed for the DC-10 and military C-5A; the latter powers aircraft like the Air Force One 747, and has a 46-million-flight-hour history. Over 1,500 LM2500s have been sold with 18 million operating hours. GE is now working on third-generation technology that will push efficiencies up another tick.

Who else is there in the heavy-lite market? Pratt & Whitney (owned by United Technologies, UTX) follows, with a 35 percent market share, distantly trailed by Rolls Royce. At the lowest power levels the group is joined by Solar Turbines (owned by Caterpillar). Aftermarket service agreements accompany about 70 percent of GE's turbine sales.

GE is equally well entrenched north and south of the sweet spot, too. To the north, steam turbines still make up half the world's electric capacity. GE remains a dominant provider, with an installed base topping 5,000 units, and just under half of the North American market for gas turbines above 60 MW. And GE has been rolling up the heavy end of the market. In the last three years, GE has acquired heavy gas turbine operations from Kvaerner (Norway), Thomassen (Netherlands), Stewart and Stevenson (Houston, TX), and from Alstom (Franco-British), the part of their operation that was a GE manufacturing licensee. The main remaining contenders: Siemens (about 30 percent of the North American market), Alstom (under 20 percent with their non-GE turbines), and Mitsubishi (around 3 percent). Won't GE's heavy-lite iron end up competing against its own heavy-iron? Undoubtedly. But GE will almost certainly earn more selling the same total power in four LM6000s aeroderivatives than one GE Frame 7. And for now, sales of GE's "frame" gas turbines, ranging from 26 to 480 MW, are still rising sharply. GE recently announced a $4 billion, 13,000 MW equipment and service deal with Duke Energy (DUK).

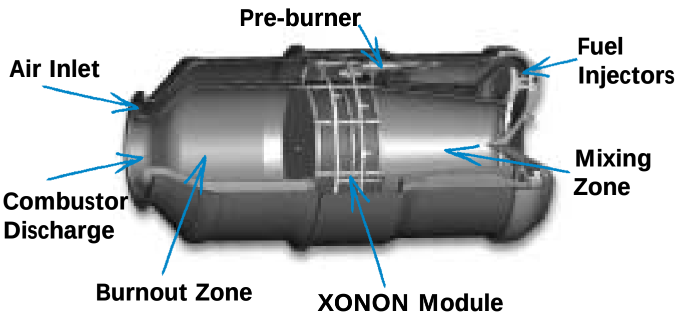
Meanwhile, south of the sweet spot, GE Distributed Power Systems produces reciprocating engines and industrial turbines ranging from 300 kW to 15 MW. At the micro-power level, GE will soon be rolling out 45, 85 and 200 kW microturbines. The one area of relative weakness for GE is in the 2 to 15 MW range. Here, Caterpillar's Solar makes 3 to 13 MW units, and owns 50 percent of that market; GE ranks second, and Rolls Royce third.

Catalytica

Clean air is the last thing standing between heavy-lite turbines and the countless substations where they might otherwise be deployed. That's what kept the power barge from docking in San Francisco Bay last summer. Gas turbines can be made to burn remarkably clean (about 19 ppm NOx), but not always clean enough for the most congested urban areas – where the demand for power is the highest, and air quality the lowest.

As we noted in the September DPR, the best thing that big fuel cells have going for them is the free (or even better-than-free) pass they get from green regulators, which they get largely because they emit almost no NOx. And they emit no NOx because they perform their fossil-fuel/air "combustion" at much lower temperatures than are encountered in a flame. The lowest-temperature fuel cells use a plantinum and/or palladium catalyst up front, to separate the carbon from the hydrogen in the fossil fuel; that sets things up for a low-temperature "burn" of carbon into carbon dioxide outside the fuel cell, and hydrogen into water inside it.

XONON Cool Combustor



Catalytica's "Xonon ("no Nox," backwards) Cool Combustion" technology accomplishes much the same thing, by putting the palladium up front of a turbine. The main difference: when all is said and done, turbine technology is a lot more mature, and runs a whole lot cheaper.

NOx is formed when temperatures hit 1,500°C, which they routinely do near an ordinary flame. In the Xonon system, about 10 percent of the input fuel is burned to pre-heat a first-stage module, in which catalytic palladium oxide particles are coated on the channel walls. The catalyst is maintained at about 450°C, hot enough to trigger the catalyltic reaction desired, but not hot enough to form NOx. The other 90 percent of the (unburned) fuel-air mixture passes over the heated catalyst, where about half of the carbon, hydrogen and oxygen molecules react — "burn," chemically speaking — but flamelessly, at below NOx-forming temperatures. The now hotter (1,000°C) semi-combusted fuel-air mixture then flows into a chamber where the remaining fuel burns spontaneously but homogeneously, raising the temperature to 1,300°C — still well below the 1,500°C temperature that triggers NOx formation. The gas entering the turbine is now as hot as it would be when it exits a conventional (NOx-creating) combustor, downstream of the (much hotter) flame. Clever. Elegant. But remarkably challenging engineering.

When it comes to squaring, megawatt-scale gas turbines with clean air, Catalytica has the solution in its revolutionary Xonon technology

The beauty of it is, the Xonon technology doesn't degrade turbine efficiency. The heat used to heat up the catalyst in the precombustor moves on down into the turbine. (In sharp contrast, heat used to accelerate emissions-control catalytic chemistry in a tail pipe gets wasted.) At the same time, the Xonon system preserves the high-inlet temperatures required for high turbine efficiency. Some NOx still does form, but (in effect) only from the 10 percent of the fuel that is burned the old-fashioned way to pre-heat the catalyst. The end result: NOx emissions remain under 2.5 ppm; emissions of carbon monoxide and unburned hydrocarbons are lower too. It's the only system demonstrated to meet emissions guidelines (in force or under review) in California and Texas without further clean-up of the exhaust downstream. Competing systems that aim to clean things up downstream of the turbine cost more, waste more energy, and are often bigger than the turbine itself.

Catalytica first demonstrated the Xonon technology over a decade ago; the company now has 19 U.S. patents granted or pending, and 43 internationally registered patents. Much of Catalytica's intellectual property surrounds the chemical, geometric, and fluid-flow factors that determine pre-heater and catalyst performance, and ensure that the exhaust from the Xonon is just the right temperature and fuel mixture to spontaneously ignite and consume the balance of the fuel, NOx-free.

With a 7,000-hour catalyst durability test in 1994, and 4,000 pre-commercial operational hours, the technology is now poised to move into commercial operation. 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.

GE is on board. After seven years of joint development of the technology, the two companies signed a collaborative commercialization agreement in 1998. Last December GE Power Systems placed its first order for Xonon units to be incorporated in four 7FA (heavy-iron, 172 MW) turbines that are headed for Enron's new 750 MW Pastoria Energy Facility in Kern County, California. GE's Nuovo Pignone subsidiary has also provided Catalytica with a "preliminary agreement" to purchase six Xonon-enabled 10 MW GE10 industrial turbines to be used by Alliance Power in co-generation and gas pipeline projects in 2002.

Since 1996, Catalytica has also had a joint development program with Solar Turbines, targeted at Solar's 5 MW Mercury 50 turbines. And a similar joint development program (also in effect since 1996) with Rolls Royce's Allison Engine division. But the first commercial Xonons will probably be integrated into Kawaski's 1.5 MW M1A13X microturbines, available in 2001. A 1.5 MW Xonon-equiped Kawasaki miniturbine is already operating on the grid at Silicon Valley Power in Santa Clara, CA – the air permit for that unit was issued in a blindingly fast 31 days. Enron has also announced a three-unit order for a small Kawasaki-Xonon DG project in the Northeast.

The last main order of business for Catalytica is a breakup. Built up over 26 years, Catalytica currently has three subsidiaries. The Xonon technology resides in the Catalytica Combustion Systems division. On August 2, Catalytica announced plans to merge with DSM, an international group of life sciences and chemical companies headquartered in Heerlen, Netherlands. The Combustion Systems unit and Catalytica Advanced Technologies, will be spun off together, to shareholders, as "Catalytica Combustion Systems" (CATX). This will leave Catalytica's third subsidiary, Catalytica Pharmaceuticals (largest current source of corporate revenue) with DSM. Consummation of the deal is currently expected before the end of the year.

Energy, Entropy, and Time

Electrons are the antidote to entropy. We devour electrons to simplify machines, cut clutter, expand choice, and extract order from the chaos of material and information that descends upon us. We consume electrons to save time, the one irreducibly scarce resource. What do we ultimately get from the electron-powered chips? Less clutter. More efficiency. More order. More time.

To pick just one illustrative example, the dismal case of the ultimate time-wasting technology: television. The nation's residential TVs and VCRs consume an average of about 200 kWh per user per year. Most of it in front of the wall, in the den itself; very little (only about 1 percent) behind the wall, in local TV transmitters, cable head-ends, and satellite distribution networks.

Now replace the VCR with a TiVo (TIVO) or a Replay TV — a CPU plus hard drive that learns your habits, checks program listings on the Web, and then (for now) trolls cable and the airwaves to download and store hours of programming. Total power consumption rises to about 300 kWh. Then substitute streaming video on the Web for the ultra-dumb broadcast and cable-cast networks, expand choice another hundred orders of magnitude — and boost per-user power to 400 to 700 kWh per user, most of it behind the wall, in the smart servers, routers, cachers, and high-bandwidth pipes. The power consumption figures play out much the same way with electronic newspaper, from paperback book to e-book, from cassette to MP3 player, from floppy to DVD to remote storage. And with countless other wired services in the great plains of e-commerce beyond.

Light bulbs and motors created the first great wave of demand for electric power a century ago; in the 1950s, air conditioning created the second. In the 1970s, many pundits persuaded themselves that it was all over — efficiency and conservation were going to take over from there on out. The efficiency of bulbs and refrigerators has indeed risen a lot faster than our demand for more light and ice. But no-more-growth futurists were wrong in assuming that bulbs and ice marked the end of new demand. The old demand was centered in electrical conductors. The new is centered in semiconductors. It is centered in silicon.

The no-growth pundits weren't completely off the mark. They sensed, correctly, that technological advance could remarkably improve the way we use and contain materials and energy. They believed, correctly again, that with better technology we could transport, manufacture, heat, cool, and light far more efficiently than we had in the past. And indeed we can. Better materials, better processes, and better digital logic, let us do a lot more with whatever raw materials we choose to use.

But overwhelmingly, these better methods — these waste-reducing, chaos-containing, order-promoting, methods — and the digital systems that manage them, are themselves powered with electricity. For good reason. Electricity is itself the purest form of energy–the least chaotic, the most ordered. In thermodynamic terms, it is almost pure "work," not "heat." Heat is lower-grade, obtained by burning traditional fuels, with about half the original energy unavoidably lost in the best thermal engines that subsequently yield higher grade kinetic energy in, say the motion of a jumbo jet through air, or the orderly flow of electrons down wires.

And it is out of energy of <u>that</u> quality – it is out of <u>electricity</u> – that we are now building a new energy infrastructure. Such rebuilds take time. But as it emerges – and it's now emerging fast — the new energy infrastructure will prove itself to be fantastically more efficient than what it will replace. It will indeed let us do a lot more with the raw materials and energy that we consume.

Whether we will then choose to consume less is a quite separate question, and beside the point for present purposes. By consuming more electricity we might indeed end up consuming less oil and gas, the primary fuels in our transportation and heating sectors. But even if that does come about – and so far, none of the bottom-line numbers lend any support to that fond hope – the consumption of electricity, and its share of our overall energy budget, will only grow. Year by year, the digital infrastructure consumes more power – a lot more. Electrons are the power of Microcosm, the power of the Telecosm, the power of the digital age.

There is no "energy crisis." There never was, and there never will be. There is, instead, an "entropy crisis," and that crisis is permanent. Life itself is a battle against dispersion, against decay, against entropy itself. The once and future scarcity is not energy, but energetic <u>order</u>, or to put it in more conventional terms, an excess of chaos, of dispersion, of negative-value entropy. And the new abundance? High-grade energy itself, together with the high-power digital logic required to control it. Megawatts on the one hand, and silicon on the other, Powercosm silicon, robust enough to choreograph electron flows on the grid in much the same way as silicon choreographs electron flows on the surface of a Pentium. The Powercosm is where energy and digital logic come together to fend off the inexorable advance of chaos, and the march of time itself.

Peter Huber & Mark Mills
October 10, 2000

We began our march through the Powercosm ten issues ago. We have since moved from the tiny to the huge, from the powerchip's microwatts to the turbine's megawatts, visiting bricks, silicon power plants, microturbines, flywheels, fuel cells, superconductors, and substations along the way. This once-through the space has helped us define the outer boundaries of the Powercosm. It's a large territory: microwatts-to-megawatts, silicon carbide to tungsten steel. But now you know where the edges lie. We've scarcely begun to explore all the space in between.

The Power Panel

Ascendant Technology	Company (Symbol)	Reference Date	Reference Price	9/29/00 Price	52wk Range	Market Cap	Customers
Power: Heavy-Iron-Lite	General Electric (GE)	9/29/00	$57 13/16	$57 13/16	38 21/100 - 60 3/4	$572b	Reliant Energy, Enron, Calpine, Trans Alta, Abener Energia, S.A.
	Catalytica (CTAL ➪ CATX)*	9/29/00	$12 3/8	$12 3/8	7 1/2 - 16 1/4	$0.7B	GE, Kawasaki Turbines, Enron, Rolls Royce, Solar Turbines
Electron Storage & Ride-Through Flywheels	Active Power (ACPW)	8/8/00	$17**	62	17 - 79 3/4	$2.3b	Enron, Broadwing, Micron Technologies, PSI Net, Corncast Cable, ABC
	Beacon Power (BCON)	IPO date pending	$11-$13**	N/A	N/A	N/A	Century Communications, Verizon, SDG&E, TLER Associates, Cox Cable
Hydrogen Generation	Proton Energy Systems (PRTN)	9/29/00	$17**	28 5/8	N/A ††	$916m	Matheson Gas, NASA
Distributed Power Generation Microturbines	Capstone Turbine Corp. (CPST)	6/29/00	$16**	69 1/4	16 - 98 1/2	$5.2b	Chevron, Williams ECU, Tokyo Gas, Reliant Energy
Fuel Cells	FuelCell Energy (FCEL)	8/25/00	49 7/8 †	96 7/32	8 - 107 3/8	$1.5b	Santa Clara, RWE and Ruhrgas (Germany), General Dynamics, LADWP
Micropower Nano-fuel cells	Manhattan Scientifics (MHTX)	8/25/00	2 3/4	3 9/32	15/16 - 8 5/8	N/A	Incubator (no customers)
Silicon Power Plants In-the-room DC and AC Power Plants	Emerson (EMR)	5/31/00	59	67	40 1/2 - 70 3/8	$28.6b	Citicorp, Verizon, Nokia, Motorola, Cisco, Exodus, Qwest, Level 3, Lucent
	Power-One	*(see below)*					
Motherboard Power Bricks, High-end DC/DC converters	Power-One (PWER)	4/28/00	34 1/8 †	60 1/2	4 7/8 - 89 13/16	$4.5b	Cisco, Nortel, Teradyne, Lucent, Ericsson
Powerchips: Insulated gate bipolar transistors (IGBTs)	IXYS (SYXI)	3/31/00	6 25/32	26 1/8	1 17/32 - 45 3/8	$639m	Rockwell, ABB, Emerson, Still GmbH Eurotherm Ltd. (UK), Alpha Technology
IGBTs	International Rectifier (IRF)	3/31/00	38 1/8	50 1/2	15 1/4 - 67 7/16	$3.1b	Nokia, Lucent, Ericcson, APC, Emerson, Intel, AMD, Ford, Siemens
	Advanced Power (APTI)	8/7/00	15	33 1/8	15 - 49 5/8	$260m	Alcatel, Ericsson, ITI, Power-One, Advanced Energy Industries, Emerson
Network Transmission and UPS: High-temperature superconductor	American Superconductor (AMSC)	9/30/99	15 3/8	49 5/32	15 9/16 - 75 1/8	$987m	ABB, Edison (Italy), ST Microelectronics, Pirelli Cables, Detroit Edison, Electricite de France

Note: This table lists technologies in the Powercosm Paradigm, and representative companies that possess the ascendant technologies. But by no means are the technologies exclusive to these companies. In keeping with our objective of providing a technology strategy report, companies appear on this list only for the core competencies, without any judgment of market price or timing. Reference Price is a company's closing stock price on the Reference Date, the date on which the Power Panel was generated for the Digital Power Report in which the company was added to the Table. All "current" stock prices and new Reference Prices/Dates are based on the closing price for the last trading day of the month prior to Digital Power Report publication. IPO reference dates, however, are the day of the IPO. Though the Reference Price/Date is of necessity prior to final editorial, printing and distribution of the Digital Power Report, no notice of company changes is given prior to publication. Huber and Mills may hold positions in companies discussed in this newsletter or listed on the panel, and may provide technology assessment services for firms that have interests in the companies.

** On August 2, Catalytica (CTAL to become CATX) announced plans to merge with DSM, (Heerlan, Netherlands). The Combustion Systems unit and Catalytica Advanced Technologies, will be spun off together, to shareholders, as "Catalytica Combustion Systems" (CATX) in December 2000. This will leave Catalytica's third subsidiary, Catalytica Pharmaceuticals (largest current source of corporate revenue) with DSM.*

*** Offering price at the time of IPO.*

† Split adjusted this issue.

†† The IPO for Proton Energy was 9/29/00, the same day as the reference date of this issue, trading range not yet established .