THE HUBER MILLS digital power report
Powering the Telecosm
July 2000/Issue 4
Published by Gilder Publishing

Jet Engines for Dot.coms

In the key segment of the power curve, on which it has chosen to focus, Capstone is well out ahead of the rest of the pack.

A jet engine to power a dot.com? Yes.

It looks like a top-of-the-line refrigerator, and runs about as quietly. In a typical high-9s configuration, it will be set up just down the hall, or in the basement, drawing its fuel from the local gas company's pipe via a standard quick-connect, with perhaps a standby tank of propane outside. Air-cooled. Very low emissions–well under 9 ppm (parts per million) of NOx, as clean as the only commercial fuel cell currently on the market.

Pull back the casing and the tiny turbine is revealed, not much bigger than a small kitchen trash can, perched on a metal framework that encloses the all-important silicon powerchips. Inside, a single shaft, spinning at 96,000 rpm, supported by air bearings that require no lubricant. Linked directly to the turbine, and spinning at the same speed, the generator puts out a steady 1600 Hz AC–unusable by any ordinary electrical equipment down the line. But the powerchips, which account for roughly one-third of the intellectual property, convert the generator's output to 480 V AC, or a DC output from 100 to 400 V.

This is the Capstone microturbine: a fantastically reliable, clean, compact, simple–in some respects "dumb"–device, made possible by uniquely smart digital logic alongside. Some 211 of Capstone's 30 kW units were shipped in 1999. Delivery time is four to six weeks. A 60 kW unit is due out later this year. For tens of thousands of small electric loads in urban areas, a gas turbine is the best option at hand for on-premises power. Better than the venerable diesel engine, which dominates the back-up generator market today. Better than the fuel cell, so widely touted as the great (and oh-so-green) hope of distributed generation.

We've been following Capstone for years. Their CEO joined us last summer to speak at a Gilder conference. On March 22 Capstone filed with the SEC to take the company public. The Company is on its "road show" as we write; and their current schedule is for an IPO in late June. The underwriters: Merrill Lynch, Morgan Stanley and Goldman Sachs.

Reliability is central

Like ducks imprinted at birth, suppliers, forecasters, analysts and planners are still determined to think about electricity supply from the perspective of the ultra-efficient, cost-optimized, monolithic central power plant. Where they stand, in the old world of Carnot, the best electron is the one that requires the least fuel to generate, the least carbon, and the fewest dollars. Show them a microturbine, and they either reject it out of hand, or set about trying to boost its thermal efficiency and lower its cost to compete with commodity kWhs from the grid. But it can't be done.

They have it backwards. The new imperative is to lose economies of scale. Lower thermal efficiency. Incur higher unit costs. Why put up with such backsliding? Because silicon demands it. Silicon demands high-9s. And high-9s require a short wire–a second, on-premises tier of generating capacity, with an independent source of fuel. The last few 9s are ultimately guaranteed by equipment that generates power at the level of individual rooms and buildings.

How much power? A typical suburban home is under 5 kW. Countless small commercial buildings currently run at 10 to 30 kW. Loads rise from there. Typical old-economy commercial buildings currently run 15 to 30 W/sq.ft. But a single rack of electronics can create a 20 kW load. And such loads are now materializing and multiply floor-by-floor, and room-by-room within existing buildings. When the silicon gets densely packed, loads easily rise to 100 W/sq.ft.

Generating capacity near the digital load either has to run continuously or be able to start up very fast. It has to be extremely reliable. It has to be cool, compact, and clean enough for the comfort of building occupants, in whose face and breathing space it is going to run. But at the same time, it must generate hefty amounts of power–enough power to keep the silicon hot, the lasers lit and the radios transmitting.

The one thing it doesn't have to be is especially efficient. It never is. Bigger turbines are always more efficient, both thermodynamically and economically. The GE Frame series hundred plus MW central station turbine (a marvel of mega engineering–the biggest is more powerful than ten 747 engines) have an efficiency of 45 percent and capital cost of $200/kW. Move down to a 25 MW FT8 Pratt & Whitney and efficiency drops to 38 percent and capital cost rises to $380/kW. The 4 MW Centaur (Solar Turbines): 28 percent and $480/kW. Capstone's 30 kW microturbine is, quite predictably, the worst of the lot: 26 percent and $1,000/kW.

This isn't just another small back-up generator, it's a quintessential 9s machine

So what? People don't buy the small units to save gas or the planet–they buy them to save their dot.com, radio base station, or mission-critical server when the grid power fails. They buy them to keep their corner of the Telecosm lit when the grid goes dark. Despite an avalanche of muddled PR and media hype, the impetus for distributed generation isn't economic deregulation or efficiency or the environment. Those factors are relevant, of course, but not central. Reliability is central. Which makes the short wire central. Which requires a generator sized to the load at hand, that can fit comfortably in the utility closet, the basement, on the roof, or in the parking lot.

For hundreds of thousands of potential sites, Capstone's fits the bill. Deployed one by one, or in redundant arrays, Capstone's 30 to 60 kW microturbines fit the huge number of sites that represent loads in the 30 to 600 kW range–the electrical loads now created by tens of thousands of high-end wireless base stations, fiber repeater shacks, digital offices, row houses, and the rapidly multiplying wired McMansions. Capstone's units have been engineered for reliability from end to end–they are simple and tremendously stable. With very high power density they are two to five times as compact as the only commercial fuel cell being sold today. And when running on natural gas, just about as clean.

First cars, now silicon

Behind the Capstone turbine stands Ake Almgren, a trim, phlegmatic Swede. He used to be president of Power Systems for ABB, a giant, diversified engineering conglomerate in Europe. Almgren oversaw leading-edge work in fuel cells, flywheels, and superconductor storage and mega-powerchip systems (sixty-foot high silicon thyristor banks) for India's transmission grid. He tried to push ABB into distributed generation, but no takers. ABB worked in gigawatts and megatons. Capstone's microturbine generates 30 kW and weighs a paltry 1,082 pounds. It would take one hundred of them just to power the water-coolant pumps in the big coal and nuclear plants that ABB used to engineer.

Founded in 1988, Capstone completed its first 24 kW microturbine in 1994. The first commercial unit, sold to Southern Union (Galveston, TX) in 1999, has since logged 12,000 continuous hours of flawless operation. Through the end of last March, Capstone had shipped 338 units that had logged some 200,000 real-world hours of operating experience; 601 more units were on order. Williams Energy has a contract to purchase 1,989 units over the next three years. Capstone's current manufacturing capacity–10,000 units a year–will double when the company relocates from the current headquarters in Woodland Hills, CA to larger premises in nearby Chatsworth.

An organization chart hangs in the reception area in Almgren's headquarters, with photographs of all his key engineers. It's a Silicon-Valley kind of line up, packed with young, multi-national talent. The power electronics group accounts for nearly one-third of the staff. How did they all happen to converge around such an elegant machine, at just the right time to serve the emergent Powercosm? It was dumb luck. That, and the engineers' blind but persistent faith that brilliant design would end up finding a market one way or another. Capstone originally set out to power cars. Then it found itself powering oil wells, and

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

transforming garbage-dump methane into electrons. Now it will power silicon.

Private investors and a former Allied Signal engineer founded the company with perhaps only one thing clear: they wanted to mass produce small turbines. In 1992, the company caught the eye of Harold Rosen, the former chief engineer for Hughes Electronics. He resolved to build a turbine-flywheel powered car. Harold and his VC brother Ben Rosen took control in 1993, brought in other investors, and formed a separate company, Rosen Motors, to build a turbine vehicle. Neat stuff. (A Capstone-powered bus has run beautifully since 1997.) But aimed at the wrong market. It's almost impossible to out-engineer Detroit within the design and price constraints imposed by the century-old automotive industry.

In 1995, Fletcher Challenge, Ltd (New Zealand) invested in Capstone; it was looking for a way to get off-grid power in remote oil and gas fields. That marked a first important shift for Capstone–to stationary applications. But, applications that were in the older-than-old economy: zero-9s oil and coal fields that weren't connected to any electric grid, and landfill and sewage plants with waste methane that might become electrons. Commercial and industrial customers bought the turbines for "cogeneration"–combined heat and power. Capstone put thirty-seven beta units in the field in 1996. Additional rounds of private funding followed, including Vulcan Northwest of the Paul Allen Group.

Meanwhile, back at ABB, Almgren watched as utilities cut in half their capital expenditures on transmission and distribution products, between 1992 and 1994. The utilities weren't generating any less electricity they were generating more. But they were turning to smaller plants–200 MW gas turbines rather than massive 1000 plus MW parks. Smaller units meant more of them, in more locations. Hence, far less demand for transmission and distribution hardware. Almgren redirected his research into smart meters, power quality, related silicon fields, power-quality technologies, and flywheels. Then he bought a Capstone turbine. A year later, on July 1, 1998, Almgren was Capstone's new CEO.

At first, Almgren was going to save the planet, just like the Rosen brothers. As he (correctly) preached, his units were small and simple, and could be located close to demand, where the "waste" heat might also be put to good use. His microturbines might also power third-world villages where there was no grid. As an "external combustion" device, a turbine can burn almost any fuel, including trash-dump gas. That appeals greatly to anyone enamored with "renewable" combustibles, and to anyone who wants to generate power in places where there is nothing but trash fuel to burn.

But the main thing Almgren had to offer was compact size and reliable ultra-low maintenance plug-and-play operation–just about as simple and hassle-free as the grid itself. And–as Almgrem would finally but firmly grasp–an independent source of extra 9s.

Size matters

As the turbine's late arrival on the power scene attests, it is quite an engineering challenge to get one to run at all. The reciprocating, external combustion engine is easiest: hence, James Watt's steam engine, invented in 1769. Reciprocating internal combustion took another century: Rudolf Diesel worked that one out in 1897. Turbines are more difficult still: the first functional units weren't built until the 1950s.

A turbine certainly *looks* simpler, and once it's finally built right, it indeed is. A reciprocating engine has far more moving parts–a veritable tangle of shafts and gears, of up-and-down pistons, rotating drive shafts, and transverse couplers. But the parts themselves are pretty simple. A turbine's complex, curved blades, by contrast, are very difficult to machine. And they have to be exceptionally strong, because they just don't generate any serious power until they're rotating very fast. A car engine redlines at 5,000 rpm; Capstone's microturbine spins at 96,000 rpm. This requires advanced materials, very sophisticated machining, and superb, high-speed bearings.

The new imperative is to lose economies of scale. Lower thermal efficiency. Incur higher unit costs.

What do you get for all that effort? A lot of power, in a very compact and ultimately simple space. That's why turbines are ubiquitous today in things that fly, as well as in modern war ships and in the 1 MW Abrams M1 tank. They're favored for a single reason: power density. Turbines are uniquely economical with space and weight. That's a huge advantage for power plants that fly. And likewise for those destined to occupy some of the most expensive terrestrial real estate on the planet, the floor-space nearest to the silicon.

But enough of an advantage? A high-9s advantage? It depends on the turbine. Aviation turbines don't supply high-9s–at least not the way the real estate market wants them. Jets and helicopters certainly require a highly reliable power plant, but they require low weight just as much, and those two objectives generally pull in opposite directions. Reliability is attained in the end, but in large part through meticulous maintenance. In the engineering itself, much in the way inherent reliability is sacrificed to reduce weight; reliability is restored through stringent and frequent inspection and replacement. Aviation turbines are built for low duty cycles and higher maintenance. The on-premises market demands high duty cycle and low maintenance.

The huge turbines built for utilities involve a different pair of trade-offs. Every last up-tick in fuel efficiency counts for producers of hundred-megawatt streams of wholesale electrons; their turbines are designed accordingly. The main way to boost efficiency is to build bigger and run hotter. So that is what manufacturers of utility-sized turbines do. Thus, they end up with stupendously big units that are far too big to fit into the places where short-wire, high-9s, electrons get generated. The utility-scale GE Frame turbines occupy acres.

The power plant destined for silicon-dense real estate has to perform a lot more like the power plant destined for the parking lot–like a delivery truck engine, in other words. Low maintenance and high-reliability are key. So why not use a truck engine? Most real estate managers that need backup power do. Caterpillar's diesel gensets are cheap and readily available, sized from 10s to 1000s of kW. Pack enough insulation, catalyst, and so forth around them, and they run pretty quiet and clean, too. But they're big and heavy compared to microturbines–that's why they aren't used to power aircraft. And diesels also require a lot more maintenance than a Capstone turbine. They just aren't an attractive package for on-the-floor, in-the-closet power. For the parking lots of Manhattan, Kansas, or Mozambique, diesels may rule for years to come. But microturbines can ride up the elevator to be installed on the tenth floor of a building in Manhattan.

Design

Capstone has twenty-four core patents. Half a dozen surround the unit's air-bearing. Comparable clusters cover the power electronics and the combustion system.

A telling fact: one-third of Capstone's engineers work on the unit's power electronics, building in the high-power digital capabilities of the new classes of MOSFET and IGBT powerchips (see April DPR). As we have argued before, the high-power digital logic of the silicon powerchip–supplied by the likes of International Rectifier or IXYS–is the linchpin to every other advance in the Powercosm. In the SynQor brick, the Power-One or Emerson silicon power plant, the powerchip is the key to transforming bad power into good, low-9s electrons into high. Almgren grasped early on that silicon works similar magic within the generator itself. Squeeze the complexity–squeeze much of the mechanical "intelligence"–out of much of the turbine itself, make do with a single shaft and no gear box, let the generator put out a ridiculously high-frequency (1600 Hz) power–pack the necessary intelligence into the silicon instead.

This was one of Almgren's key contributions to Capstone. At ABB he had directed the development of one the world's first multi-MW solid-state transfer switches. Before his arrival, Capstone had directed much of its R&D at optimizing thermal efficiency and contriving clever mechanical solutions. Almgren recognized the inescapable importance of air bearings, but put equal emphasis on building up the powerchip team. And it's mainly in the silicon that Capstone has since solved the problem of interfacing turbine and 1600 Hz generator to ordinary AC and DC loads, and accommodating variations in load. Within a single, integrated unit, Capstone now combines short-wire electrons with a powerchip-based silicon power plant/UPS.

The Capstone microturbine's solid-state electronics solve another refractory problem of AC power engineering centers. As discussed in the June DPR, AC power sources and their loads often interact very badly: get them out of sync by the smallest amount, and waves of power "harmonics" go crashing up and down the wires. A unique and ingenious feature of Capstone's turbine is that when the grid is up, the silicon auto-synchronizes with it–the power electronics were designed from the start to do so. This makes for perfectly seamless connection to, or disconnection from, the grid–or to and from sibling microturbines running alongside. Neither the grid above, nor the load below, is disrupted by the hand-offs.

Capstone's air bearing–a "gas foil bearing" to engineering purists–is the unit's single most important mechanical feature. Air bearing technology first surfaced in the 1950s and '60s, to meet the need for ultra-high-speed fuel pumps on military aircraft. Oil bearings don't hold up well at very high speeds–the oil gets too hot, breaks down, and requires frequent replacement. Air bearings dispense with almost all moving parts–lift is developed by the flow of the air trapped and compressed between the shaped, almost micro-wing-like "foils" and the shaft–so the bearings are essentially maintenance-free ridding on air. The first commercial air bearings were produced for the DC-10's Environmental Control System (ECS) in 1969; all aircraft built since 1988 have air foil air bearings in the ECS, a close cousin of the microturbine. The Boeing 747's have a 100,000-hour MTBF (mean time between failure). Capstone has refined the technology and manufacturing process; it keeps the details of its design and fabrication a closely guarded secret. Almgren, once again, has the right background for this kind of engineering. He learned the business of high-volume, zero-defect manufacturing of complex parts–automotive airbags–in the course of a two-year detour from ABB as President of Autoliv, an Electrolux-group company.

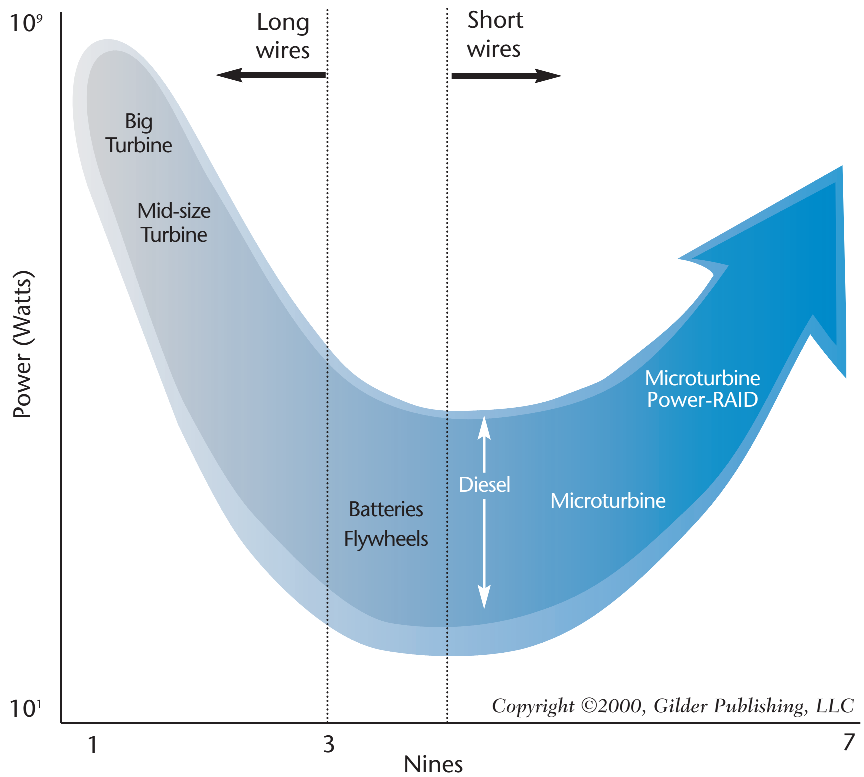
Capstone, alone, has likewise completely eliminated liquid coolants, from both turbine and generator. It has pushed down the turbine's operating temperature to 1100ºF–considerably cooler than the 1500ºF of a giant GE turbine. In the megaturbines, higher temperature yields thermodynamic efficiency; in Captstone's micro, lower temperature yields simplicity and reliability.

Lower temperatures make for cleaner burning, too. Hotter combustion means more nitrogen burns along with the fuel, which means more NOx in the emissions. As in all chemical reactions, NOx formation is extremely sensitive to temperature–a 400ºF drop leads to a huge reduction in NOx formation. Capstone's NOx is rated at under 9 ppm, and real-world measurements indicate that it's even cleaner than that. A unit installed to burn methane at the world's second largest landfill in Puente Hills, CA emits 1.3 ppm, which ranks it as a "zero emission" machine. (Big diesels often operate in the 1,000 plus ppm range.) The complete absence of oil lubricants in the Capstone turbine also eliminates any trace of oil in the exhaust.

Finally, in the configuration of most interest to the Powercosm, the Capstone turbine runs on an exceptionally lean natural gas fuel mix. This further lowers combustion temperature down to 1100ºF. Capstone uses three fuel injectors, a configuration generally found only in mega-turbines. Patents on the combustion chamber design and the unit's lean fuel mix make up another part of Capstone's key intellectual property.

If there is a single main point of vulnerability to a Capstone system, it lies in the pressure of the gas line. If it isn't high enough a compressor is needed. As equipment goes, however, these compressors (which Capstone itself can supply) are tried and true.

Raising Power 9s



Big turbines and long-wires (the backbone electric grid) are inherently low-9s. Reliabilty (9s) rises as the size of power sources shrink and move closer to the load. But silicon loads in the Powercosm now rival old economy levels of demand creating markets for a new architecture of short-wire, hot swappable, microturbine-based Power-RAIDs.

Seamless handoffs

The Powercosm is about the chasm that separates grid electrons from silicon electrons. As discussed in the May DPR, the challenge on the circuit board is to push the power "brick" up the power curve, to 100 Watts and higher. But fifty feet away, at the level of the room or building, the challenge is to downsize a generator to fit the on-premises load. The space of opportunity for Powercosm companies lies between the 200W circuit boards and 200 MW utility-sized generators. The 9s will come from power generating and conditioning units situated in between.

In addressing this space, it is better to start with a module that is smaller than the load, not bigger. With the right power-electronics at hand to switch and synchronize available generators, it is relatively straightforward to assemble such modules into a Power-RAID–a Redundant Array of Independent (Power) Devices–that pushes both power and reliability much higher than each single module delivers. N+1 redundancy of subcomponents is the key to reliability throughout the Telecosm; the same architecture makes sense, for the same reasons, in the Powercosm.

Capstone's microturbines can be configured in just this way–as an N+1 array of microturbines provides hot-swappable high-9s power. No single power plant, however bullet proof, can ever match such a configuration for reliability. When one unit drops out of the array, the hot-running "+1" unit picks up the load, auto-synching seamlessly. The failed unit is rolled out on a hand cart; a new one is rolled in to replace it. This is less thermodynamically efficient than using a single power plant that is N times as large. But it is considerably more reliable. And in the Powercosm, the 9s rule.

At the margin, a hot-running Power-RAID can displace the endlessly troublesome banks of lead-acid batteries. The main purpose of batteries is to supply "ride through" electrons that cover the premises between the time when the grid goes down and the backup generator fires up. For a cold start diesel, that means tens of seconds, or longer. Because of its air bearings, a microturbine's cold startup takes longer–but because it runs so quiet, clean and maintenance free, the microturbine can instead be kept hot and spinning. This takes more gas but less lead and acid, less floor space, and less maintenance.

There are of course limits to how far hot-running redundancy can usefully be pushed; at some point complexity begins to rise, power density begins to decline, and reliability begins to decline too, as more units are added to an array. But a 30 kW building block happens to be a very good size to start out with. Arrays of 10 to 20 such units will match loads in 300 to 600 kW range (and the 60 kW unit captures the 600 to 1,200 kW range)– just where a very large number of silicon rooms and buildings now land. Capstone recently shipped the first of two 10-packs to a New York plastics fabricator. With the full 600 kW capability in hand, the frustrated manufacturer plans to go off grid entirely.

The microturbine can readily ride up the elevator to be installed on the tenth floor of a building in Manhattan.

As more power is needed, plug-and-play scalability is easy. It is, indeed, a lot easier to build up higher levels of power than higher levels of MIPS: power electrons are inherently additive; generators provide highly scalable power. The challenge here is to scale down, not to scale up–scale down to land on the right part of power curve to match loads encountered in the fastest growing range of silicon loads. Which is exactly where Capstone has positioned its generator.

Other players

There are only a handful of other contenders in Capstone's space. None is a pure play in Powercosm technologies.

Honeywell (formerly Allied Signal) builds the beautiful, 75 kW "Parallon" unit. Like Capstone's, it runs on an air bearing, though unlike Capstone's, it still has a liquid-cooled generator. It runs somewhat hotter and somewhat dirtier (officially rated at <50 ppm NOx). (By comparison, multi-MW turbines are typically rated at over 25 ppm NOx). Honeywell is also shipping products–the first commercial unit shipped in 1999. Honeywell recently announced the sale of "as many as" 55 units to ComEd, to back-up a senior housing facility in Chicago. In total, Honeywell reports 150 sales; not yet in Capstone's league, but significant progress in what is still a very young market.

Like Capstone, Honeywell has insisted, until recently, on touting the cheap-green-power virtues of on-site generation, but Honeywell, too, now seems to have recognized the far greater promise of high-9s market. Customers are getting the message. West Jet Airlines, a regional Canadian airline, recently purchased a Honeywell Parallon 75 to back up its call center. The company's Power Unit is headed up by the very sharp Tony Prophet. All the signs for the Parallon are great–all but one. We wonder whether a giant like Honeywell can ever really unleash its Power Unit to serve the silicon world, which invariably demands delivery today, tomorrow being way too late.

Elliott Energy Systems (Jeanette, PA, private firm) is another microturbine contender. It builds oil-bearing, liquid-cooled 35, 45, 60 and 80 kw units. Next year they will have a 200 kw unit available. Units delivered to date lack a recuperator (unlike Capstone's, where additional intellectual property lies), which is needed to keep the relatively inefficient small turbine from being a complete disaster in fuel-use terms. The Elliott unit has emissions comparable to Parallon but several fold higher than Capstone's. And it uses old-world gears to drive a generator on a separate shaft.

Ingersoll-Rand Energy Systems (Portsmouth, NH) is another player. It builds the PowerWorks family of liquid-cooled, two-shaft microturbines. Full-scale production for the 70 kw is expected late in 2001 and the 250 kw in 2002. The company seems very focused on the green advantages of cogeneration, and is determined to exploit synergies with other Ingersoll products, like compressors and chillers. Turbec, a Volvo/ABB joint venture, says it will introduce a 100 kW, liquid-cooled unit this year. Their focus, again, seems to be on cogeneration, not high-9s. Toyota has demonstrated two conceptual designs of liquid-cooled micro, 50 kW and 250 kW units; the current plan seems to be to drop the 50 kW unit and focus on the 250 kW unit.

Move out of the ambit of the <100 kW microturbine, and the next stop takes you to units in the >1000kW range. Great advances in units of this size have been spurred by the development of cruise missiles. Williams International, progenitor of early cruise missile engines, makes an astounding garbage-can-sized 100 kW small aviation engine–aimed (for now) at low-cost commercial aviation jet-powered son-of-Cessna. In the next few years, units (or arrays of units) of this size (1,000 kW to 50,000 kW) are going to be deployed in large numbers on rooftops and in parking lots, in direct competition with the marine diesels more commonly used there now. Among some other contenders in this space: Teledyne Continental Motors (Toledo, OH) and Pratt & Whitney.

The next step up the power curve is another giant one–up two more orders of magnitude, to the General Electric and Siemens-Westinghouse family of beasts where the smallest utility-scale units are in the 100 MW range. They're magnificent machines–and generate 4000 plus times more power than a Capstone. They are, in short, grid-level machines, long-wire machines, and thus–inevitably and inescapably–rooted in the low-9s universe. Only in a sprawling grid–or a jet aircraft–is there enough collective demand to match a 100 MW output. GE turbines power commercial jets, too. Just don't think of trying to install one in your dot.com.

Forging alliances

When software crashes, vendors often get away with calling the bugs features, and life goes on. Crashing a disk drive is a more serious matter. Crashing a backup generator more serious still. Machines that bridge the space between Carnot and Moore take longer to build, and have to run far more stably and for much longer, than those centered entirely on the silicon side of the divide. Hands-on, real-world experience matters a lot more in the Powercosm. And in the key segment of the power curve on which it has chosen to focus, Capstone is well out ahead of the rest of the pack.

So much for supply; how about the demand? As a company in the throes of an IPO, Capstone can't paint castles in the sky. We can. Here's just one; the fecund imagination of high-9s market will come up with many others.

The 300 kW silicon load becomes as common as the grocery store or gas station. It is fueled by cheap low-9s grid power, on the one hand, backed up in parallel by seven 60 kW Capstones on the other. All feeding silicon power plants (see June DPR) to deliver high-9s to the silicon load. Five Capstones run hot (partly loaded); number 6 is on hot-standby (unloaded, spooled and ready for a rapid ramp), number 7 on cold stand-by. A fraction-of-a-second hiccup in grid power? The flywheel inertia inherent in the spinning Capstones rides through it, without recourse to battery banks or additional flywheels. A multi-second sag in grid power? Five hot Capstones go immediately to full load with their powerchips shipping constant clean power. Capstone Number 5 has a problem? Hot-standby number 6 takes over automatically, its powerchips once again ensuring a seamless hand-off, auto-synchronizing with the other running turbines, the load, and the grid. Number 7 on cold stand-by fires up to go on hot stand-by. Number 5 shuts down, invisible to the silicon. In short order it's quick-disconnected, wheeled into the elevator, and sent down to the loading dock. A replacement is already on its way from the local Capstone distributor, who has been automatically notified that a local Capstone has shut down. Within hours, a new cold-standby replacement is wheeled out of the elevator, and quick-connected into departed Number 5's empty slot.

Duplicate the array so one Power-RAID becomes your own source of commodity kWh and the other the parallel back-up, and you go off grid; higher cost to be sure, but there will be plenty of markets where that doesn't matter, or where it may be cheaper. The RAID high-9s hot-swap architecture migrates from where it is common in the racks of smartchips and is echoed now on bigger 'racks' of powerchip-enabled microturbines.

Far-fetched scenarios? Not in places where staying hot really matters. This is precisely those places that handle their multi-gigabit disk storage today, however unlikely such a prospect would have seemed to mainframe engineers a decade ago. The Power-RAID is equally inevitable, now. Nothing else can deliver the 9s.

The Powercosm presents the really enormous potential for Capstone's growth in our view, and we believe the company has come around to that view, too. Capstone cut its teeth in older markets, and isn't too proud to continue serving them. Its units have been configured to burn trash, garbage-dump methane, and the highly corrosive sour gas that vents from oil fields. They can burn diesel oil or kerosene, and burn it lean, and therefore clean.

People don't buy the small units to save gas or the planet–they buy them to save their dot.com, radio base station, or mission-critical server when the grid power fails,

Capstone is now forging strong alliances with large resellers that will target every potential market. In March, Capstone signed an agreement with Meidensha Corp. (a $1.8 billion electric equipment manufacturer) and Sumitomo Corp., both in Japan, to distribute the microturbines in a combined heat and power system. Sumitomo will import the Capstone and build a nationwide (Japan) network for maintenance. On April 28, Capstone announced the industrial giant Mitsubishi would be a distributor in Japan and Asia.

In all, Capstone has lined up a commanding lead in distribution partners with twenty-seven distributors in seven countries, including sixteen distributors in the U.S. and six in Japan. More are in the pipeline. Even a few traditional old economy electric companies made the leap: Allegheny Energy (PA), and Pennsylvania Power & Light (not surprisingly, PA is the first state to truly deregulate electricity), and Alliant Energy, (Madison, WI). Also on the list of distributors is the paradigmatically-correct Alternate Energy Corporation (Cumberland, RI), which is also a sales rep for the ONSI fuel cell, and a rep for Toshiba's AC silicon power plants (UPSs). Joining the distributor network team are also companies already deep in to the structural markets of DG such as Interstate Power Systems (Minneapolis MN) which distributes Detroit Diesel Engines, and Waukesha-Pearce (world's largest Waukesha engine distributor). Also on the list: the successful new economy wholesale electron player, AES Crop (Houston, TX) which formed a subsidiary, NewEnergy to compete in deregulated markets.

Ake Almgren's 1998 move from ABB to Capstone was the equivalent, roughly speaking, of IBM's chief

The Power Panel

Ascendant Technology	Company (Symbol)	Reference Date	Reference Price	6/26/00 Price*	52wk Range	Market Cap	Customers
Distributed Power Generation Microturbines	Capstone Turbine Corp. ** (CPST)	6/29/00	TBD	TBD	N/A	N/A	Chevron, Williams ECU, Tokyo Gas, Harbec Plastics
Silicon Power Plants In-the-room DC and AC Power Plants	Emerson (EMR)	5/31/00	59	63 3/16	40 1/2 - 65 7/8	$27b	Citicorp, NTC, GTE Wireless, Nokia, Motorola, Cisco, Exodus, Qwest, Level 3, Lucent, etc.)
	Power-One (PWER)	*(see below)*					
Motherboard Power Bricks, High-end DC/DC converters	Power-One (PWER)	4/28/00	68 1/4	116 3/8	9 3/4 - 116 3/8	$4.25b	Cisco, Nortel, Teradyne, Lucent, Ericsson
Powerchips: Insulated gate bipolar transistors (IGBTs)	IXYS (SYXI)	3/31/00	13 9/16	62 9/16	3 1/16 - 62 9/16	$751m	Rockwell, ABB, Emerson, Still GmbH Eurotherm Ltd. (UK), Alpha Technology
IGBTs	International Rectifier (IRF)	3/31/00	38 1/8	53 1/2	11 3/16 - 53 1/2	$3.2b	Nokia, Lucent, Ericcson, APC, Emerson, Intel, AMD, Ford, Siemens
Network Transmission and UPS: High-temperature superconductor	American Superconductor (AMSC)	9/30/99	15 3/8	45	11 13/16 - 75 1/8	$860m	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 judgement 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. 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.

* *This month's Digital Power Report was printed prior to the end of the month. The current price for the July report is the press date rather than the last day of the month as is the usual practice.*

** *At the time this publication went to press, Capstone Turbine's initial public offering had not yet been completed.*

engineer moving to Dell–in 1984. Microturbines and other short-wire generators are where the PC suppliers were back then, aware of the potential for huge demand, but still guessing and groping their way toward meeting it. Capstone doesn't yet know just how customers will deploy its microturbines; the customers themselves are still working that out.

Only this much is certain: great engineers have latched on to a stealth revolution in materials, manufacturing, and powerchips to create a Powercosm product quite unlike anything that has been built before. Nothing like the technology inside the units that Capstone is rolling off its assembly lines today existed when Capstone was founded twelve years ago. This isn't just a another small back-up generator, it's a quintessential 9s machine, more compact, quiet, clean, mechanically reliable, and electrically stable than anything that has come before. It is as different from a 1980s back-up diesel generator as a Palm Pilot is different from Apple's SE30 of similar vintage.

No single date in history records the moment when distributed computing overtook the mainframe as the economic epicenter; none will record the moment when distributed power overtakes the grid. And indeed, the "overtaking" is entirely relative; reborn as Web server, the mainframe is processing more MIPS than ever before, just as the grid is (and will continue) to move more electrons, year after year.

But for all that, a fundamental, organic, and powerfully disruptive shift in the Powercosm is now under way. Capstone is perfectly positioned as a leading-edge disruptor in the expanding new cosmos of the electron.

Peter Huber & Mark Mills
June 26, 2000