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Electron Spin

Active Power stands almost alone as a pure play with the right technology (heavy-and-slow) in the right space (ride-through), at the right time (now)

From the outside, the off-white cabinet looks much like Power-One's DC silicon power plant or Capstone's microturbine. Inside is the kinetic-energy equivalent of a Mack truck rolling at 50 mph: two 600-pound steel flywheels, stacked vertically, and spinning silently in a vacuum at 7,700 rpm. Each is integrated with a motor/generator on a single shaft, supported on state-of-the-art magnetic bearings. In the top part of the cabinet, is an array of large powerchips, poised to release the kinetic energy as a 500 kW flood of pure electrons. This is the "CleanSource Flywheel Energy Storage System," manufactured by Active Power of Austin, Texas.

ABC uses a couple to clean up the power for a microwave transmitter on the 32nd floor of its New York data center. Broadwing (a Cincinnati Bell ISP) has a unit to provide a "ride-through" power bridge between its racks of servers and a Detroit Diesel generator. (Floor space was a key factor going with a flywheel rather than batteries.) Micron Technologies (Idaho) installed two Active Power units to replace aging batteries on a UPS. Other customers include PSI Net (in an ISP hotel), Peterson AFB (space command data center), Fairview Hospital in Cleveland, OH (computer center), and Comcast Cable.

CEO Joe Pinkerton founded Active Power as Magnetic Bearings Technology in August 1992. Its first commercial sale of a flywheel was to Southern Company in early 1997. After rigorous testing, the buyer installed the unit alongside an Exide UPS to solve a severe power quality problem for sixteen Computer-Numeric-Controlled machines in a Fort Walton (Florida) shop. With two years under its belt, the flywheel has since supplied some 300,000 pulses of ride-through electrons. Nearly 100 other Active units are now up and running for other high-9s customers with a cumulative 250,000 hours of operation.

Why now? As energy storage devices go, the flywheel is the most primitive. The potters of Pompeii used foot-power to turn massive stone flywheels that supplied a steady spin for their clay. Flywheels on crankshafts have been used since the nineteenth century to smooth out the "boom" and "thump" of a piston engine. What customer could possibly want to park a ton or so of this ancient technology smack in the middle of digital microprocessors, lasers, CDMA radios, and optical switches?

It gets worse. All right-thinking designers of "high tech" flywheels have been pursuing tiny, light-weight wheels, made from exotic carbon fiber and levitated entirely on exotic magnetic bearings. Joe Pinkerton uses comparatively big and heavy wheels made from plain old steel. Most of the rest push rotational speeds up toward 100,000 rpm. Pinkerton's units creep along below 8,000 rpm. Many of the others aspire to save the planet, by building a kinetic-storage substitute for gasoline in cars. Pinkerton builds only for stationary platforms. The light-and-fast crowd see their still experimental wares featured in the glossy pages of *Discover, Fortune,* and *Popular Science* magazines. *Wired* magazine hyperventilates over a flywheel company funded by Kevin Costner. Pinkerton doesn't attract gee-whiz press. But we'll give him ours.

We don't chase IPOs, but for the second month running an IPO has landed in the center of our turf. We noted Active Power in a May 1999 article in *Forbes*, then again in the introductory issue of this newsletter last September (www.powercosm.com). The company's IPO (ACPW) is now scheduled for August 7. The underwriters: Morgan Stanley, Merrill Lynch, Goldman Sachs and CIBC.

The battery: virtues and vices

We visited our first telephone company central office fifteen years ago. There, sprawled across some of the most expensive real estate in the country, in a building already packed with digital switches, fiber optic lines, and the budding infrastructure of the digital telecosm, we found an entire upper floor of … lead-acid batteries. Hundreds of them, arrayed on tables and shelves, all vaguely redolent of vinegar.

A battery still starts your car–most of the time. And the world's largest purchaser of lead acid batteries is, of course, General Motors, a company of little consequence to the Powercosm. Correction: Make that American Power Conversion (APCC), one of the world's leading providers of uninterruptible power supplies (May DPR). The lead they used to put in your gasoline now simmers in acid on your desktop. Burgeoning demand for heavy-duty, high-power batteries has pushed delivery times for telecom/datacom centers out to a year.

The battery's one great virtue: it is a zero-inertia device. When a battery is alive and kicking, it can kick instantly. At its best, a battery is a reservoir of electrons, able to pour them out on demand during the grid's millisecond hiccups, and then on (if necessary) through the long seconds or even minutes that it takes for a stand-by generator to spin up to speed when the grid goes down completely. Electrochemical systems can do milliseconds. Electromechanical systems can't.

Except that isn't quite right, either. A mechanical system's inertia can work for you as easily as it can work against you. In principle, at least, it's the easiest thing in the world to transform high inertia into almost instantaneous electrical response–just keep the mass moving, the shaft turning and the generator spinning.

The market opportunity if you do? Replace some significant fraction of the millions of batteries sold each year to provide ride-through electrons in silicon power plants and UPSs. For stationary ride-through applications in rooms and buildings–in the hundred kW to multi-MW level ranges–the right flywheel is better than a battery. Not just a bit better, but an order of magnitude better. More compact. More reliable. Much easier to monitor. And far less demanding, in terms of maintenance and replacement.

The company that has the right flywheel is Active Power.

Batteries aren't dead

The two most common failings of grid power are spikes and dips. Spikes–an excess of electrons–you cut up and throw away. Not always trivial, especially if the spike is a lightning bolt–but smart switches, dumb capacitors, and even dumber wires (leading straight to ground) can generally do the job. Dips–a dearth of power–are usually a tougher challenge. This problem requires an instantaneous source of electrons–and often, lots of them.

As a general rule, the more electrons you need, the longer it takes to deliver them. Take a day to fire up a gigawatt coal boiler, and you can have all the electrons you want. A CPU can be kept lit from one clock cycle to the next by an array of tiny tantalum capacitors parked right on the motherboard. For Powercosm purposes, the toughest challenges lie between these two poles, where substantial amounts of power are required very fast, to keep racks, floors, and entire buildings lit during the grid's frequent and inevitable dips, and for the many more seconds it can take to start a back-up generator.

Batteries are the overwhelmingly dominant ride-through technology of Powercosm today. They're everywhere–vast arrays of them, packed densely into cabinets, or stacked floor to ceiling on heavy duty steel racks. The real estate set aside for large UPS's–100 to 1,000 kW AC and DC silicon power plants–is dominated by lead and acid, not silicon. For every 500 kW of system silicon you will find about five tons of batteries nearby. There are batteries in every wireless base station and in every optical head-end. Some 249 batteries on steel racks stand behind the planet's most precise atomic clock in Boulder, Colorado. This blend of twenty-first century atomic physics, computers, and communications pipes looks like … a Delco warehouse.

Hundreds of millions of dollars have been poured into the U.S. Advanced Battery Consortium, in search of the Holy Grail, a battery-powered car. Lead is a loser. So nickel-metal-hydride, perhaps? Or lithium? The only unambiguous result so far: No car. No big surprise there either, not to people who know batteries. All in all, batteries remain an inherently fat, heavy, cumbersome, recalcitrant low-9s technology. The only way to get reliable power out of them is by way of massive redundancy, wasting weight, space, and the time it takes for painstaking monitoring, maintenance, and replacement.

The battery's low DC voltage is an advantage when you're very close to the smartchip digital load–as in a cell phone or laptop. But floor and building-level back-up power can't be distributed across the premises at 1.5 volts. To push voltages up to practical levels, battery backup systems typically employ two cabinets each containing 20 of the 12 V batteries, or a rack containing 240 of the more common 2 V batteries to yield the 480 V base voltage. Multiple arrays are often mounted in parallel to meet the power requirements and provide

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redundancy for high-end systems. If one fails by shorting open, it can bring down the whole array with it.

The battery's limits are the opposite of the grid's. Batteries don't dip or spike, right out in the open, for all to see. Instead, they degrade slowly and secretly. They have malignant memories. Short charge-discharge cycles can sharply but invisibly reduce the amount of energy they store. Discharge them too often, too deeply, and they get chemically asthmatic, and never perform well again. Thinner electrodes improve performance but also lower energy density and life expectancy. Almost all batteries have finite lives, though again they are adept at concealing their senescence. Batteries are environmentally sensitive–they don't like extreme cold or heat. And the environment doesn't like batteries. Almost all consist of chemical soups of varying degrees of toxicity. Disposal of dead batteries–batteries do keep dying, remember–is now viewed as a serious environmental problem. The EPA is on the case.

The upshot of all this is that batteries typically have to be stacked on prime real estate very near the digital loads, where it's warm, and where the battery chemists can hover over them like nurses in the intensive care unit of a hospital. And we are talking a lot of real estate. Batteries are relatively low-density devices in the one dimension that matters the most–their ability to unload their stored energy very fast. Given the value of real estate in a Powercosm hotel (up to $1,000 per rentable sq. ft.), a substitute technology that required much less of it would be very attractive, even if batteries were both utterly reliable and free.

No, batteries aren't going to disappear. They serve a huge, rapidly growing market. Battery technology is improving on many fronts. For a wide number of applications–portable, mobile and remote ones most notably –they remain a much better option than any alternative, flywheels included. With that said, the case for the flywheel begins with the battery, and all that's wrong with it. Which is a lot. The potential size of the flywheel market: some significant share of the over $1 billion, and growing ride-through market that batteries currently own.

Active Power's CleanSource

The concept is obvious. Spin a flywheel up to speed using junk power from the grid, when it's available. At such times, the unit's wiring operates as an electric motor–electrons in, momentum out. When the grid dips or sags, flip the same wiring instantaneously from "motor" to "generator" mode–momentum in, electrons out. Capacitors in the electronics alongside offset the millisecond delays inherent in the inductive inertia in the flywheel generator's own wires; the kinetic energy in the steel does the rest.

Flywheels can deliver power from what is, or least can be, fairly simple, familiar technology. Most of the basic elements of a flywheel ride-through system are readily available from multiple vendors. This is especially so at the heavy-and-slow end of the flywheel space, where Active Power has positioned itself. After all, flywheels, shafts, bearings, and motor generators are found all over the place, in engines, pumps, ship gyroscopes, and navigation equipment.

In Active Power's CleanSource, an array of IGBTs keep the voltage rock-steady at 480 V DC, the gold standard of the Powercosm

So why haven't people been using flywheel generators for decades? While a flywheel is mechanically clean, elegant, and simple, the electrical power it produces is junk. A battery offers a perfectly steady DC voltage; a flywheel, a congenitally unsteady AC, that decays in both frequency and voltage as the flywheel slows down. Which it must do, of course, when you draw power from it.

But transforming, variable-voltage, variable-frequency junk power into power as clean and steady as a battery's has recently become quite easy: just pile up silicon above the generator. In Active Power's CleanSource, an array of IGBTs (some from International Rectifier, others from Siemens) keep the voltage rock-steady at 480 V DC, the gold standard of the Powercosm. Active Power uses an especially neat design trick to make this happen: its silicon powerchips boost the current in the generator's magnetic field-inducing coils as the rotational speed decays. The powerchips likewise stabilize the generator's frequency, which (on its own) would decay from about 1,000 Hz at 8,000 rpm to 250 Hz at 1,000 rpm.

In many mid-9s applications, nothing more than the flywheel is needed. The vast majority of computer-crashing outages are very short, and a good ride-through system will raise power quality enough for many users' purposes. Not enough to cover the much rarer hour-long outages, but enough to cover most of the almost daily incidents that would otherwise blue-screen monitors throughout the building. Where longer outages are unacceptable too, back-up generators will fire up in time to take over as the flywheel winds down. (The CleanSource also has a separate 24 V output, which can back-up or replace the standard 24 V battery required to start a back-up generator–battery failure is the single most common reason for the failure of back-up power.)

Either way, a flywheel can be marvelously clean, compact, and reliable. A flywheel only emits a modest amount of heat, which is carried away by a redundant array of fans, and footprints have been reduced more than ten-fold–thanks to silicon. Older designs could only use the top 5 percent or so of the flywheel's energy, before the frequency and voltage decayed to unusable levels. Active Power's powerchips recapture 94 percent of the stored kinetic energy, and (after losses in the silicon itself) deliver 80 percent of it to the load. Silicon has thus boosted the flywheel's usable-energy density over fifteen-fold. Silicon's impact on batteries, by contrast, has been much more modest. The main improvements have come from better load management (putting laptops into sleep mode, for example), improved duty cycles, and better tracking of the battery's state.

Most importantly of all, a flywheel can deliver its stored energy fast–much faster than a battery can. (Think of the pairs of numbers that follow as the total miles you can get from a tank of gas versus the 0-to-60 acceleration – the former, energy, the latter, power.) A CleanSource flywheel with 1 kWh of kinetic energy can release almost all of it in about 15 seconds–which is to say, at a power level of 250 kW. That's a power-to-energy ratio of 250 to 1. A typical lead-acid battery, by contrast, can't do much better than a ratio of 10 to 1. It can store about 1 kWh–enough energy for a 10 second 500 kW ride-through–but its own innards prevent it from actually delivering 500 kW for more than a tiny fraction of a second. Too rapid discharge crowds the battery's plates with chemical by-products, and it slips into a gas-induced coma. Leave it alone for an hour, and it will wake up again. But that's not much use, a diesel or generator can wake up in an hour, too.

Of course it's possible to stack up enough batteries to provide 500 kW ride-through, but only at an enormous price in weight and space. With batteries, you meet the power requirements only by deploying a massive excess of energy. The higher the power-to-energy ratio, the better suited the technology is for ride-through applications. Batteries readily match or beat flywheels in most (not all) applications where total energy matters as much (or more) as short-term power. But they can't come close for ride-through.

This simple metric establishes the basic case for flywheels versus batteries–and likewise lets us divide the flywheel crowd into two camps, those that get it and those that don't. The latter are chasing batteries in the energy storage market, not in the power ride-through market. Flywheels can (and do, as we note further below) compete usefully in the energy storage space too, in applications that are highly sensitive to weight (e.g. in satellites), and in applications that are highly sensitive to the cost of monitoring and replacement. But for the most part, flywheels have a long way to go before they become serious contenders in the energy storage space. In the ride-through space, by contrast, they are already far beyond "contender"–they outperform batteries today, by an order of magnitude or more on the performance criteria that matter the most.

Only a tiny handful of companies has emerged so far with real flywheels targeted at the right space in the Powercosm. ActivePower is one. A second is Piller Premium Power Systems (Middletown, NY)–a private company with roots in electric power reaching back to 1909, but now part of the RWE conglomerate of companies in Osterode, Germany. A third, HITEC (formerly Holec Power), which is owned by Industrial Marine Diesels (Netherlands). And perhaps also in these ranks: Beacon Power, still private, and 30 percent owned by its original parent, SatCon (SATC, Cambridge, MA). Beacon just finished a second round of private financing, raising $28 million from GE Capital, Mechanical Technology Inc (MKTY), DQE (sponsors of American Superconductor's first install in Detroit), Penske Corp., Perseus Capital and Arete Corp., among others. We expect an IPO within months. Watch for it.

The rest of the flywheel gang is comprised of a grab-bag of start-ups, still in R&D, or the beta phase of development: U.S. Flywheel (Newbury Park, CA), American Flywheel (Seattle, WA), which recently acquired Trinity Flywheel (San Francisco), which had itself been spun out of the Lawrence Livermore Labs. Others include, Acumentrics (Westwood, MA), Optimal Energy (Torrance, CA), RPM (Irvine, CA), Flywheel Energy Systems (Nepean, Ontario, Canada), and a host of DARPA, Department of Defense, NASA, and university-based projects and teams. Most are aiming their wheels at a much more difficult and distant market, one that excites journalists and government funding agencies a lot more than it excites potential customers in urgent need of solutions today.

For now, Active Power stands almost alone as a pure play with the right technology (heavy-and-slow) in the right space (ride-through), at the right time (now). Today is a time of soaring demand for just what Active offers: a robust, commercially proven product of elegant design, built from just the right technology, and surrounded by a reasonable (though hardly impregnable) picket fence of patents. This is no JDS Uniphase. It's a Compaq or a Dell, smartly run and smartly positioned in a market that is poised to grow very fast indeed.

Design strategy: speed, size and weight

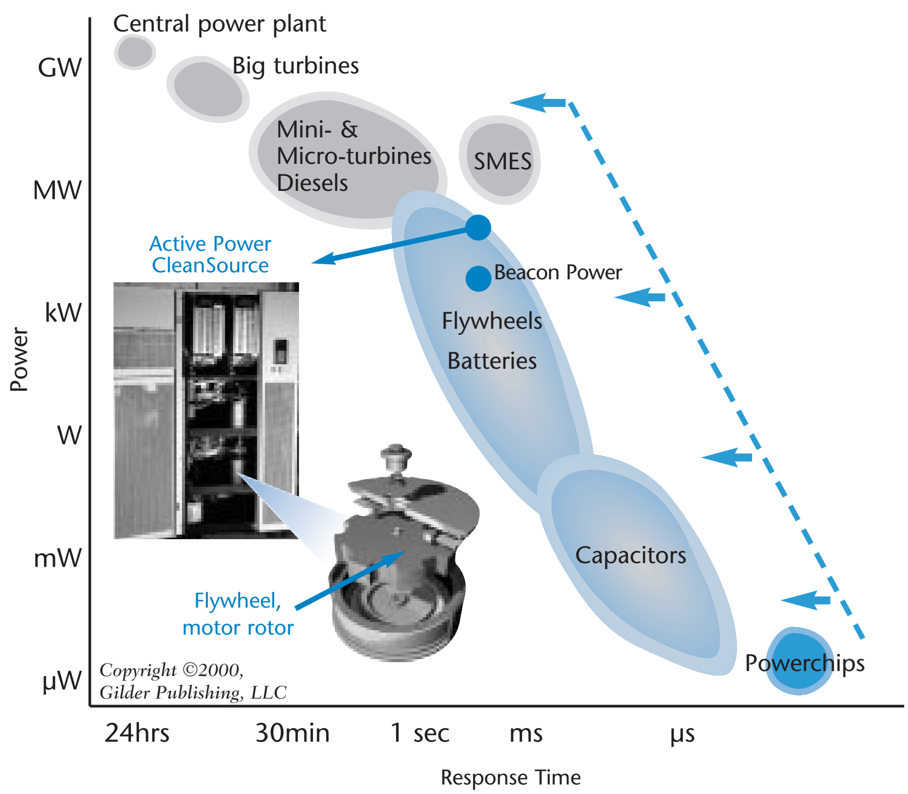
Many of the best flywheel designers have spent their best years chasing Detroit. For quite a time, flywheel-stored energy was going to replace the internal combustion engine. Chrysler built a Le Mans race car, turbine powered and flywheel-accelerated. Engineering professors and students on government grants designed flywheel-powered buses. Capstone (July DPR) started out aiming for the automotive space. Before moving into the Powercosm, it came to grieve in its attempts to mate a flywheel to its turbine.

The energy of a flywheel increases with its density–steel stores more energy than carbon fiber. But a flywheel destined for a moving platform has to be light. It's no use storing more energy in a heavier flywheel if you then have to consume that same energy hauling around the flywheel's own heavy carcass. The core challenge is to use the flywheel's inertia to overcome the inertia of car-plus-flywheel. A tough challenge indeed.

It can be done, of course–in theory, at least. One way is simply to increase the flywheel's radius and concentrate the weight on the distant outer rim. For a standard cylindrical flywheel, energy rises (or falls) as the fourth power of the radius. On moving platforms, space is severely limited and a small footprint is as essential too. So for years, flywheel designers aimed for both small and light. But reducing both weight and radius entails fierce reductions in the amount of stored energy. All that's left to get the energy levels back up again is speed–the wheel's energy also increases as the square of the rotational speed. So in designing for a mobile platform, the designer has to push rotational speeds up and up, to the brink of centrifugal self-destruction.

For most flywheel companies that was and remains the core design strategy: smaller, lighter (graphite fiber) and ultra-high speed. Optimal Energy Systems is prototyping a 100-pound system containing a forty-thousand rpm flywheel. Trinity uses a 50-pound flywheel spinning at 40,600 rpm. U.S. Flywheels uses a 30-pounder with a 100,000 rpm target.

Ride-through electrons



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

These very high speeds, however, create tremendous stresses within the flywheel itself, on the bearings that support it, and on the components that surround it. High speed strains all the key interfaces, where the wheel bonds to the shaft on which it spins, or to the permanent magnets embedded in it which generate current in the surrounding wires. The light-and-fast designers favor carbon fiber over steel, for example, because its lower density (bad, for energy storage purposes) is offset by higher strength (essential for spinning faster). Shaft bearings are another big problem–the ultra-high speeds strain the outer limits of magnetic-bearing technology. Ultra-high speeds also require a very "hard" (and therefore hard-to-maintain) vacuum to reduce drag on the wheel's surface. But a hard vacuum makes it more difficult to dissipate heat, which is generated by friction in the bearings and electrical resistance in the components of the generator. Where weight does matter (satellites) titanium is used (by Optimal Energy, for example) for the metal components.

High speed also raises safety concerns. If the flywheel self-destructs, or the bearings abruptly fail, your spinning mass becomes a cannon or a grenade. The challenge of maintaining the mechanical integrity of spinning metal was solved long ago in routine applications like turbines and reciprocating engines – which operate at the kinds of speeds at which Active Power operates. But ultra high-speed flywheels present altogether new challenges.

Yes, they're all being overcome, inch by inch. But only one manufacturer of high-speed wheels has made a commercial sale, and that's Beacon, which just landed its first commercial order this past February. And Beacon happens to be the one company that straddles the two spaces. Beacon's 200-pound carbon fiber flywheel spins at 20,000 rpm–which makes it light and fast compared to Active's, but heavy and slow compared to the rest. Beacon, as we shall see, is indeed on a very promising track.

Pinkerton founds Active Power

In 1989, fresh out of Columbia and Albion College (MI) with a degree in applied physics, Joe Pinkerton signed on with FRC, a small, private R&D firm just outside Detroit, Michigan. (FRC was working closely with the University of Texas, one of the nation's top centers for high-end electromechanical machines. UT has since supplied a dozen or so of Active Power's top engineering talent.) While at FRC, Pinkerton conceived a unique design for a passive magnetic bearing–since incorporated as a key component of Active's CleanSource flywheel.

Pinkerton launched Magnetic Bearings Technology in August 1992, with funding from Eric Jones (SSM Ventures). (Enron–a company with a sharp eye for opportunity in the Powercosm–participated in Active's most recent round of venture funding.) Four years later, Magnetic Bearings renamed itself Active Power and began designing flywheels exclusively and specifically for stationary ride-through. After shipping its first commercial unit in 1997, Active Power refined and expanded the technology, began shipping units to commercial customers around the world, and set about forging key marketing alliances with several leading manufacturers of silicon power plants–Emerson/Leibert, Powerware, and MGE (See May DPR).

Pinkerton ignored carbon fibers, the seductions of federal funding and the temptation to tilt at windmills in Detroit; he aimed straight for the vast space occupied by batteries

By aiming at the right market–stationary, ride-through applications–Active simply sidestepped most of the problems that have bedeviled developers of high-speed flywheels for moving platforms. Pinkerton ignored carbon fibers, ignored the seductions of federal funding and ignored the temptation to tilt at windmills in Detroit; instead, he aimed straight for the vast space (both physical and economic) occupied, but so poorly served, by batteries.

Active Power machines its rotor (flywheel and shaft) from a single piece of forged 4340 stainless steel. There are no permanent magnets and no wiring in the flywheel itself–because it's made of metal, eddy currents in the flywheel's own teeth suffice to create the magnetic field that induces current in the stationary wires surrounding the wheel. (See Figure) The generator contains no other components and no other parts susceptible to failure. At 7,700 rpm, CleanSource's relatively low speed allows the use of standard bearings, combined with the stress-relieving and friction-reducing feature of a main magnetic bearing that partially levitates the flywheel and thus reduces loads on the mechanical bearing. The overall design is truly elegant. Equally important, the materials, the (few) moving parts, the loadings, and the speeds, are all drawn from the solidly established mainstream of mechanical engineering. Active does not have to push out anywhere close to the well-established limits of material strength or bearing technology.

This makes us quite sanguine about safety. One suitably spectacular failure–one that scatters limbs and bodies about a room–will certainly put a young flywheel company permanently out of business. But we don't expect to see one. Steel wheels rotate in millions of large engines and motors, in factories and on ships. Unlike their high-speed carbon fiber cousins, Active's steel flywheels are built according to robust engineering and safety standards–standards established by national engineering societies on the basis of long and in-depth real-world experience. The discipline is so mature that modern rotating machines (including jet engines) are typically built with operating-to-yield-stress safety margins of 1.2 to 1.3. Active builds to a margin of 2.5.

All of which makes the CleanSource big and heavy compared to … well, compared to the technology that no one has yet mastered, the super-high-speed, low-radius, light-weight carbon fiber flywheel. Compared to the battery, however, a one-ton CleanSource system is a wonder of miniaturization and light-weight design. A CleanSource occupies 10 square feet and replaces 5 tons and 40 square feet of batteries on racks or in cabinets. A 250 kW CleanSource sells for about the same installed cost as the industry-standard battery configuration it replaces–$45,000. But the CleanSource's maintenance costs are far lower. Its state is easy to monitor, precisely and continuously. Speed, which determines how much kinetic energy the system contains at any moment, is easy to track. So are signs of friction and wear–multiple accelerometers monitor shaft vibration, and thermistors monitor operating temperatures. And every "discharge event" is precisely logged by Windows-based software, allowing detailed trend analysis of the flywheel's health.

In 1999, Active entered into a strategic partnership with Caterpillar; Cat now has worldwide rights to distribute an integrated, co-branded 250 kW UPS. The unit combines Active's flywheel with a rapid-start Cat diesel generator and UPS electronics in a turnkey package (in a ready-to-roll, trailer-mount configuration) for the industrial and manufacturing marketplace. We expect to see Active in other alliances with manufacturers of back-up generators. Microturbines present a natural opportunity for another alliance; the CleanSource can indeed be viewed as a short-haul turbine that relies on momentum rather than burning gas as its primary source of energy. That detail aside, flywheels and turbines have much the same, single-shaft architecture, depend on much the same power electronics, and are perfect complements in their response times.

Active Power owns 21 patents, with 9 more pending. Roughly 10 relate to the flywheel itself. The rest address a range of other aspects of the design: the magnetic bearings, integration to reduce the duplication of components and increase power density, and power electronics. For all that, Active Power's genius doesn't lie in wildly new technology, it lies in elegant design and perfectly timed execution. This is engineering, not physics. But so is Dell.

Beacon Power straddles markets

How about the rest of the pack?

In the heavy-and-slow space, HITEC has opted to sell only fully integrated UPS/backup system: a 4,500 rpm flywheel-integrated motor-generator, and Detroit Diesel backup engine, all bundled into a single package. Individual units come in sizes up to a very high-end 1.5 MW package. HITEC sold its first (20kW) unit in 1956; it has installed over 500 systems and 200,000 MW of UPS capacity since. The company recently took delivery of its 1000th diesel, destined for a multi-module array purchased by AboveNet Communications, in San Jose, CA. Last year HITEC launched a UPS rental service, which provides emergency, maintenance, or temporary installations of 120 kW to 1,000 kW. Exodus recently broke ground on its first battery-free Powercosm hotel (fall completion), to be built around a HITEC unit.

Established in 1991 to meet the rising demand for high-end UPS, Piller likewise makes a fully integrated flywheel/fast-start diesel generator, in sizes that run up to a 10-second, 1,650 kW, 22-ton unit. Unlike HITEC, the Piller flywheel is a physically separate component (akin to Active's) – a 5-ton unit that supplies 10 seconds of 1.6 MW ride-through. Designed and built on the same philosophy as Active's CleanSource, Piller's unit spins at a very slow 3,600 rpm. High-end Piller systems can now be found in data centers around the world.

With flywheel ratings from 150 kW up to 1,670 kW, Piller is certainly Active's, closest competitor. Piller anchors the bottom of the heavy-and-slow paradigm–heavier than Active and even slower. But Piller doesn't sell a "plug compatible" straight replacement for battery sets. With Piller, you have to take it all: flywheel, UPS, and generator. Turnkey packages have advantages, and Piller makes a good one. But Active's customers can mix and match; they can keep an existing UPS and just replace the batteries. They can take their pick of back-up generator among diesels, turbines, and even fuel cells, or (in mid-9s applications) they can forego the backup generator entirely. HITEC and Piller are both going to prosper. But our guess is that Active's modular, plug-and-play design will provide an easier, more versatile fit to the very broad range of configurations in which batteries are now deployed.

Then finally, there's Beacon Power, the straddle company. Like Active, Beacon is building a stationary platform and targeting battery replacement. Unlike Active, it's aiming to provide energy storage on top of ride-through–in places where the flywheel's edge over batteries centers on transparency, durability, and reliable remote monitoring. Beacon's flywheels are configured to provide several kWh of continuous power, for up to several hours, for distributed end-point telecom applications where the unreliability and maintenance demands of battery systems are a serious liability.

Like Active, Beacon has made consistently good calls in engineering design and market targeting. Its package fits in an oil-drum-sized vacuum container, and it is being deployed in places where it can be buried–which takes care of all lingering concern about safety. With over a dozen patents in hand, Beacon's first commercial prototype went into operation in late 1998 for WinDBreak Cable (a small cable TV company in Nebraska). Beacon has other orders in hand from Cox Cable and SDG&E, as well as a $1.5 million production order from TLER Associates (a Mexican telecom).

Beacon's buried flywheel, offers the promise of the zero maintenance, one-hundred percent operational transparency, and easy remote monitoring

Beacon is also working closely with Verizon (formerly Bell Atlantic), to develop units for their 20,000 fiber-to-copper remote terminal sites. Verizon currently uses the best batteries that money can buy (about $4,000 per terminal), but must periodically dispatch technicians to maintain and replace them at all 20,000 locations. Beacon's buried flywheel, by contrast, offers the promise of zero maintenance, 100 percent operational transparency, and easy remote monitoring. Beacon has completed real-world field trials with Verizon, with over 10,000 hours logged on the two units. Two production representative units are to be shipped to a Philadelphia terminal next month . Current price: about $15,000 each, with two needed to replace the batteries. That makes their up-front capital cost much higher than the batteries they'll replace. But the difference should be more than offset by the flywheel's much longer life, far lower operating cost, operational transparency, and higher reliability. And according to Bill Stanton, Beacon's president, prices should drop to well under $10,000 as production volumes rise.

The only way to invest in Beacon today is indirectly, through the one-third ownership founder SatCon (SATC) retains. As it happens other SatCon interests include a strong focus on powerchip modules for telecom applications (see April DPR), silicon wafer fabs, factory automation and aircraft and automotive sectors. But we just haven't had occasion to drill into those aspects of SatCon to plumb their alignment with the Powercosm.

The Power Panel

Ascendant Technology	Company (Symbol)	Reference Date	Reference Price	7/21/00 Price*	52wk Range	Market Cap	Customers
Electron Storage & Ride-Through Flywheels	Active Power (ACPW)**	8/7/00	$11-$13***	N/A	N/A	N/A	Enron, Broadwing, Micron Technologies, PSI Net, Corncast Cable, ABC
	Beacon Power**	IPO TBD	N/A	N/A	N/A	N/A	Century Communications, Verizon, SDG&E, TLER Associates, Cox Cable
Distributed Power Generation Microturbines	Capstone Turbine Corp. (CPST)	6/29/00	$16***	57 9/16	27 3/8 - 68 3/4	$4.2b	Chevron, Williams ECU, Tokyo Gas, Harbec Plastics
Silicon Power Plants In-the-room DC and AC Power Plants	Emerson (EMR)	5/31/00	59	65 1/8	40 1/2 - 65 7/8	$27.8b	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	139	9 3/4 - 160	$5.07b	Cisco, Nortel, Teradyne, Lucent, Ericsson
Powerchips: Insulated gate bipolar transistors (IGBTs)	IXYS (SYXI)	3/31/00	13 9/16	66	3 1/16 - 90 3/4	$802m	Rockwell, ABB, Emerson, Still GmbH Eurotherm Ltd. (UK), Alpha Technology
IGBTs	International Rectifier (IRF)	3/31/00	38 1/8	61 7/8	12 3/86 - 65 1/2	$3.8b	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	51 1/8	11 13/16 - 75 1/8	$1.01b	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.

** Because this month's Digital Power Report was printed prior to the end of the month, the reference date for the August Report is the last trading day prior to the press date rather than the last day of the month as is the usual practice.*

*** At the time this publication went to press, Active Power's IPO was scheduled for August 7, 2000. Beacon Power has not yet scheduled an IPO.*

**** The offering price on the date of the IPO.*

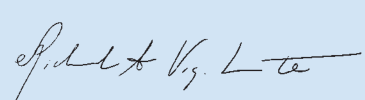
And the rest of the flywheel crowd? Some, like Optimal Energy Systems, are aiming for–and may yet find–a niche market in applications like satellites. NASA will tolerate exotic bearings and titanium casings–one-of-a-kind solutions for a one-of-a-kind space station. In time, no doubt, the relentless drive of talented engineers will yield viable light-and-fast flywheels for mainstream, earth-bound applications, too.

But for now, there's no contest. The heavy-and-slow flywheel easily beats the light-and-fast competition–every bit as easily as it beats the still heavier-and-slower, battery. Active and Beacon have found the sweet spots.

Peter Huber & Mark Mills
July 24, 2000

Dear Subscriber,

We are pleased to announce that electronic access to current, as well as previous issues, of the *Digital Power Report* will commence with the October issue. Watch this space for more details next month.



Richard Vigilante
Publisher