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Pontiacs and Powerchips

The electrification of the automotive drive train over the next decade or two portends a roughly hundred-fold increase in demand for powerchips

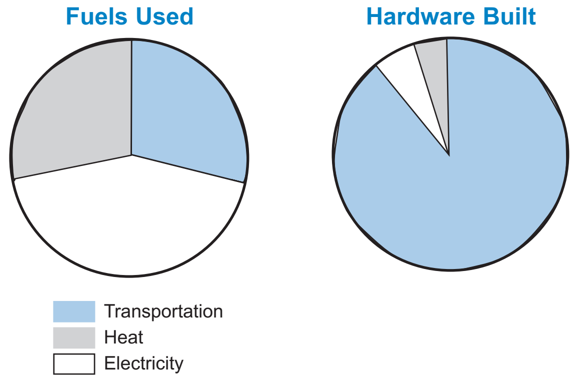
Picture a vast parking lot filled with 10,000 Pontiacs—not little cars, but real wheels that your average American would be proud to drive. At exactly the same moment every single driver turns the ignition key, shifts into neutral, floors the accelerator, and 10,000 Pontiac engines go screaming up to the red line on the tachometer. All together, those Pontiacs are now generating about 1 gigawatt of power. Which is about as much power as flows down a few dozen high-voltage lines from a decent-sized electric power plant, operating at full power on a typical summer day.

For America as a whole, we have, at one end of the parking lot, some two hundred million Pontiacs and comparable power-plants-on-wheels. If we ran them flat out, all the time, they would burn five to ten times as much fuel as the two or three thousand-odd electric power plants sitting at the other end of the lot. But the electric power plants in fact burn more fuel, and produce much more useful power, because they run very efficiently, around the clock, and at close to peak capacity for many hours of the day.

In the overall picture, alongside the Pontiac and the power plant, there's the oven or furnace—a simple source of plain old heat. Heat, which defines the third principal sector of our energy economy, is about the same size as the transportation sector. The thermal sector uses furnaces, ovens, dryers, and welders to heat air, water, foods, and chemicals, to cure paints and glues, to forge steel, and to weld ships.

The future of energy technology comes down to one overarching trend and one key paradox. The trend is electrification: the backplane of an Intel server, which is already all-electric, to the drive train of the Pontiac, which is headed that way, electricity is the ascendant "fuel" of our energy economy. The paradox is that the automotive sector consumes barely 30 percent of all our energy but builds about 90 percent of our energy conversion technology. (See Figure 1.) Thus, while the automotive sector is certainly the last of the three main sectors to embrace the electric drive train, the technologies that electrify the distribution of power under the hood of the car will ultimately dominate electrical power processing everywhere.

Figure 1. Anual Energy Conversion:

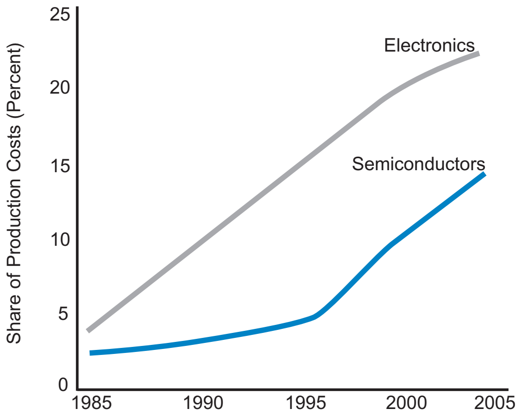


Source: Energy Information Administration Annual Energy Review 2000.

The energy tech companies to invest in for the long haul are those that can meet Detroit's unique demand for high volume, low cost, and exceptional reliability. They will prosper by earning atypically solid margins supplying Detroit (and Stuttgart) with the technologies needed to electrify brakes, steering, pumps, valves, suspension, and ultimately the wheels—everything downstream of the internal combustion engine. Very profitable margins are now opening up between the old mechanical-hydraulic power distribution systems, on which the automotive sector has relied for the better part of a century, and the electrical systems that now offer at least tenfold improvements in speed, precision, reliability, fuel economy, and environmental performance.

What is equally important—and equally new—is that these same manufacturers will quickly come to dominate the rest of the energy-tech sector as well—the power-related tiers of

Figure 2. Silicon and Electronics in the Automobile



Source: Bosch, courtesy DaimlerChrysler.

industrial machines, consumer products, and information technology. Intel (INTC) developed its microprocessors for desktop computers but ended up selling them for cars, cell phones, and microwaves. The companies that come to dominate the market for automotive power processors will end up selling them to factories, offices, and homes. The big telecom story of the current decade is the convergence of telephony, cable, and broadcasting into a single, digital, broadband market. The big energy-tech story will be the convergence of the automotive, industrial, and electrical sectors.

The Silicon Car

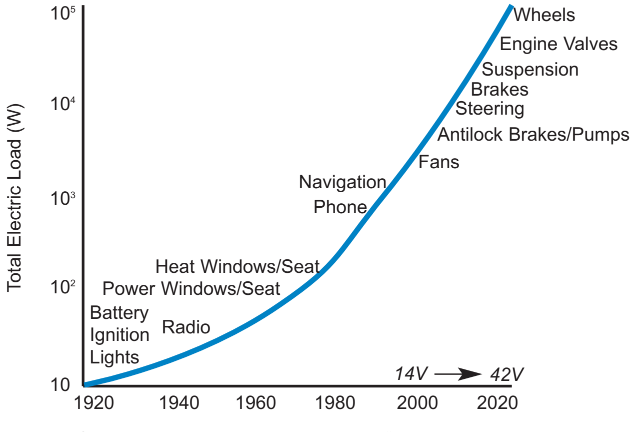
We first wrote about the electrification of the automotive power train almost two years ago (*Powerchip Paradigm II: Broadband Power and The Silicon Car, December 2000*). It's been a long time coming, and the transition will take at least a decade to complete. But it is a trend that is now firmly underway, and it is the paradigmatic, transformative trend in energy technology for our times.

Etienne Lenoir and Nikolaus Otto built the first electro-thermo-mechanical control systems for their spark ignition engines, and Henry Ford incorporated their basic designs in the Model T. In due course, the hand crank and magneto gave way to a battery and 6-V grid (standard until the 1950s), then to a 12-V grid, which quietly became the 14-V grid (when the engine is running) in today's vehicles. The grid of the modern car is now quite elaborate—over 5,000 feet (70 pounds) of copper wire link hundreds of connectors, five-dozen fuses, dozens of relays and sensors, 50 to 100 MOSFET powerchips, and a clutch of microprocessors. All the chips run about $350; in total, the power electronics account for about 20 percent of the typical car's cost. (See Figure 2.) Detroit now spends much more on silicon than on steel, and the silicon share keeps rising. Electric demand on the automobile platform is now rising about 4 percent per year. The total electric load now runs about 1 kW, with a peak load up to 2 kW.

But that's still not much, in the larger scheme of things. The real power train in the Buick is the 100 kW (peak)/20 kW (average) mechanical one—the one that begins at the piston rods, and ultimately powers the wheels, and almost everything else in the vehicle. This gap between 2 kW and 100 kW defines the opportunity for truly radical change in the coming decade. (See Figure 3.)

The November 2002 issue of *Technology Review* ("Why Not a 40-MPG SUV?") reviews the technologies that form the core of the electric drive train. While the article has a typically academic emphasis on saving oil and the planet, it gets all the key engineering trends just right. (The Society of Automotive Engineering (SAE) likewise titled its July 2002 editorial "Sustainable Development: The Time Is Now"; today's engineers, it seems, are only permitted to boast about the planet-saving implications of their ingenuity.) As the *Technology Review* piece correctly notes, the technologies of the 40-mpg SUV are already at hand. "[M]any of these technologies are based on the conventional internal-combustion engine. They don't

Figure 3. Electrification of the Auto



Source: Kasakian, Miller, and Traub, "Automotive Electronics Power Up," IEEE Spectrum *(May 2000).*

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require complex electric-gas hybrid drive trains … nor are they based on anything as exotic as fuel cells.” The most radical advance will come from all-electric valves replacing the camshaft, with software-driven control for each valve, but there are countless other shifts from mechanical to electrical controls and power delivery systems that will, collectively, have an even larger impact. The more arcane journals of the Institute of Electrical and Electronics Engineers (IEEE—See Table 5.) have been mapping out the same story as well, for some time now. It is, in fact, fair to say that the domains of the IEEE and the SAE are now rapidly converging. As we write this issue, electronics and automotive engineers are gathering in Detroit for their annual “Convergence Conference,” which draws more than 10,000 attendees.

Electrons, silicon, and software are of course critical to driver entertainment and information systems and other convenience features in the passenger cabin, and they likewise control and activate safety systems. But they are now extending far more broadly, to accommodate a much wider range of demand for power levels, precision, and speed—from radar-based active cruise control to high-power electric valve actuation. The once relatively simple task of getting 12 volts to the spark plugs, headlights, and dashboard has given way to managing a complex, multi-tiered electric grid and control system. (See Table 1.) The change is happening now because it depends on low-cost logic, low-cost accurate sensors, and high-performance powerchips. (See Figure 4.) The latter—the critical MOSFETs and IGBTs—have only recently matured to the point where they can handle high power, and do so efficiently and on the tremendously hostile and demanding automotive platform.

Table 1. Automotive Power Electronics

Category	Peak Power	Typical Applications
Driver Info, Entertainment	1 kW	Phone, GPS, Displays, TV, Radio, Audio; PC, DVD; IR vision; Millimeter-wave radar (cruise, near-object detection, parking); On-board/remote diagnostics
Body & Convenience	5 kW	Powered door locks, mirrors; Distributed interior fans; Heated windows, mirrors; Powered rear seats (fold down); Climate-controlled seats; Powered doors, trunks, hood spoiler to deflect bugs, cargo conveyor belt; Powered swing-out steps
Safety & Vehicle Dynamics	15 kW	Electrohydraulic steering; Rear electric steering; Front electric steering; Electrohydraulic brakes; All-electric brakes; Regenerative braking; Antilock brakes; Adaptive/active suspension; Active roll-over avoidance; Active traction control; Adaptive air bags; Active cruise control; Active head light aiming; “Pre-safe” active interior*
Power Train	100 kW	Integrated starter/alternator; Intelligent cooling; Intelligent lubrication; Catalytic converter pre-heat; Electric AC compressor; Active engine mounts; Active vibration control; Electric valves; Direct fuel injection; Electric throttle; Electric turbocharger; Electric drive wheels

* Radar-triggered automatic pre-positioning of bumpers, steering wheel, doors, seats, interior door panels, etc.

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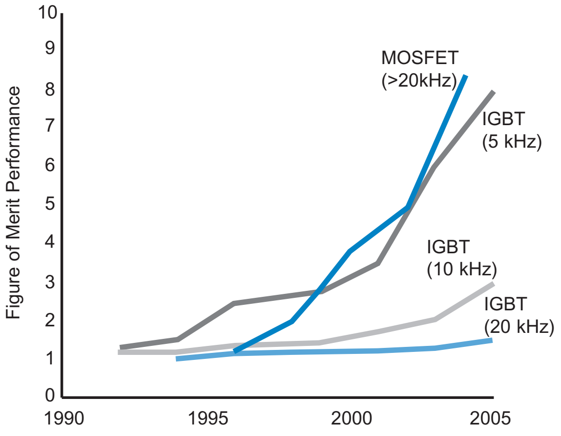
Figure 4. Powerchip Performance



The Figure of Merit is a blended measure of performance criteria ranging from the basic silicon gates to the package. The central goal is to switch power rapidly with near-zero losses in the switching itself, and in the “on” state, and near-zero leakage in the “off” state. IGBTs are used for power levels 10 to 100 times higher than MOSFETs.

Source: Lidow, A. et al., “The Semiconductor Roadmap for Power Management in the New Millennium,” Proceedings of the IEEE (June 2001).

The transition to a fully electrified automotive drive train will take many years, of course. But all of the key engineering and social indicators now suggest that it will happen faster than many suppose. Electrification provides radically better performance and will soon provide it at lower cost, even while it addresses political and environmental demands for more efficiency and lower emissions. Several percentage points (just one “point” is a big deal in the auto world) in incremental gains in efficiency and emissions reductions come with every step in electrification. Once they get started, fundamental transitions to better, faster, cheaper, and cleaner technologies tend to accelerate rapidly.

In the end, silicon-controlled electric power will knock out the entire gear box, drive shaft, differential, and related hardware—all of which disappear when direct electric drives finally end up turning the wheels. At that point, the entire output of the engine—anywhere from 20 kW to 100 kW or more—will be converted immediately into electricity and distributed directly to electric motors (and storage devices) throughout the car. It matters much less than most would imagine how those 100 kW are produced—

whether hydrogen fuel cells, batteries charged at night from coal plants, or oil-fired internal combustion engines. Indeed in the former two cases, the silicon drive train must come first. What matters the most is how the 100 kW are conveyed and used to drive, control, and ensure safety. It will take heavy-duty wiring and substantial silicon drives and electric motors to propel an electric SUV down a highway at 70 mph—but they'll still be far smaller than the steel structures in today's power train. (See Figure 5.) Cars will shed many hundreds of pounds, and every key aspect of performance will improve considerably.

As we have noted before, all-electric drives already control fighter jets and submarines. Diesel-electric trains are already powered by an enormous diesel-fueled engine-driven generator; everything beyond is electric; so are monster mining trucks, in which everything, right down to the 12-foot wheels, is driven electrically. Electric drives are taking over because an electrical bus can convey far more power in much smaller, lighter conduits and convey it far more precisely and reliably than even the best designed mechanical drive train.

All of these developments are necessary if Detroit is ever to make a decisive shift from the internal-combustion engine, but whether or when that shift ever happens is quite beside the point, for our purposes. Silicon is smarter and faster than gears, linkages, and valves, however elaborately they may be shaped and assembled. An electric wire is far lighter and more compact than a metal shaft conveying the same amount of power. With the functionality of digital power technologies rising and their costs dropping by factors of two or more every few years, the only issue is when, not if, the silicon will displace completely the steel drive train. Whether or not we ever trade oil for hydrogen-powered fuel cells, or lithium batteries, we will first trade a lot of steel for silicon.

Table 2. Automotive Semiconductors: Logic

Company	Revenues	Website
Bosch (6041.DE)	$33b	www.bosch.com
Hitachi (HIT)	$60b	www.hitachi.com
Infineon (IFX)	$6b	www.infineon.com
Intel (INTC)	$27b	www.intel.com
Mitsubishi Electric (MIELY.PK)	$27b	www.mitsubishielectric.com
Motorola (MOT)	$30b	www.motorola.com
NEC (NIPNY)	$43b	www.nec.com
Philips (PHG)	$32b	www.philips.com
STMicroelectronics (STM)	$6b	www.st.com
Texas Instruments (TXN)	$8b	www.ti.com
Toshiba (TSBAa.BE)	$41b	www.toshiba.com

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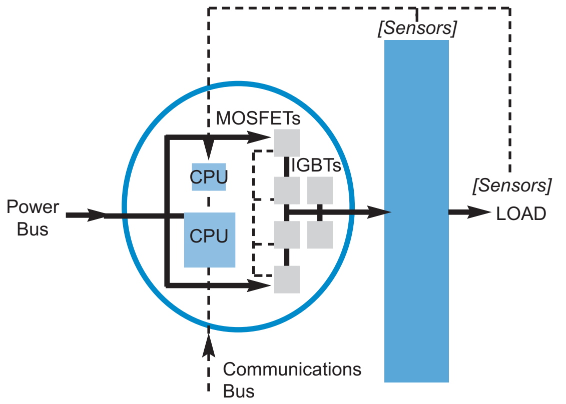
Figure 5. Silicon Driver



Silicon-Car Companies

The companies that will move the silicon into the car fall, roughly, into four main groups.

The first group doesn't do power; it does logic and communications. Microsoft (MSFT), for example. The Redmond giant's Automotive Business Unit isn't just pursuing the in-dash PC, e-mail, Web browser, and PDA; it correctly foresees an entire new class of applications for linking and processing data streams generated by sensors distributed all through the car. Keyboard, mouse, and modem give way to streams of data relating to what the car has done, will do, and needs done to it. Automotive sensors already define a market of about $7 billion per year; the average car has $130 in sensors alone, and the volumes of data traffic flowing among the drive train, the driver, and the world at large will continue to double and redouble every few years, indefinitely into the future. Other companies in this group include manufacturers of digital radios, navigation systems, and so forth.

The second group comprises the suppliers of control logic—chips, software, and communications buses—that run more or less autonomously under the hood. (See Table 2.) Motorola (MOT) and Infineon (IFX) are the two leaders with over 20 percent of the market between them. A typical car requires a dozen or so microprocessor control units (MCUs)—relatively inexpensive, robust, specialized microprocessors of limited power (typically running at 100 to 300 MHz); a luxury vehicle requires dozens more. The first MCUs controlled fuel injection; today they also modulate brake pressure (for antilock braking), control locks, antitheft devices, engine diagnostics, and a growing array of other functions. About one-dozen companies control two-thirds of the $11-billion auto-logic market. Motorola has about four times Intel's market share, in the automotive MCU marketplace.

The third group is populated by the traditional "Tier 1" suppliers of automotive components; drive trains, cooling systems, engine valves, brake systems, seats, dashboards, etc. (See Table 3.) The main U.S. players are the likes of Delphi (DPH), Visteon (VC), Lear (LEA), Dana (DCN), Eaton (ETN), and TRW (TRW). All of these companies are already pushing power silicon into the modules and components that they manufacture and will do so at accelerating pace over the course of the next decade. They fully grasp that the shift from mechanical and hydraulic to electric power presents them with a unique, market-transforming opportunity to slash costs, expand margins, and capture secure positions in any market segment that they may come to dominate. Mechanical and hydraulic systems have to be custom designed for almost every platform, and there are thousands of quite different platforms. Electrical systems cut much more easily across platforms; they thus offer the possibility of near-monopoly economies of scope and scale to the companies that capture the early lead, and then expand it, the way Intel and Microsoft did in their own markets a decade or two ago.

Among Tier 1 suppliers, Delphi and Visteon both remain largely captive of GM and Ford, their respective former parents. TRW is particularly interesting because it does so much defense work, where much of the leading-edge power technology is pioneered. (After Northrop Grumman (NOC) completes its acquisition of TRW, watch closely for who ends up acquiring TRW's world-class automotive electronics and controls units in the expected spin-out of those operations.) Lear's business is already squarely centered in power electronics, but most of what it sells goes into such areas as dashboards, switches, and wipers—car "interiors," not the higher power applications where the digital-power action will be centered going forward.

Dana and Eaton are the two most interesting unaffiliated large, pure-play Tier 1 suppliers. Dana is exclusively an auto supplier—a weakness from our perspective—but could branch out into other markets as its automotive-electric products mature, and the company has just announced an intriguing alliance with Emerson Electric (EMR) to develop motor-based actuators. The $10-billion Dana is a major manufacturer of drive shafts, which are destined, eventually, to go the way of the buggy whip, but the company is moving aggressively into silicon-based intelligent water pumps and steering modules. For its part, Eaton has a solid base in car and truck components, but also builds power systems that span a wide range of military, aviation, and industrial applications. Through its Cutler Hammer division, for example, Eaton is also an important manufacturer of electric power distribution equipment. Any investor betting on the large crosscutting energy-tech trends should give Eaton a serious look. The casual observer will see an old-economy power components company; to us, however, it looks like a company well positioned to capture and exploit the cross-market opportunities created by the ascendance of digital-electric power trains.

Table 3. Some Tier One Auto Suppliers

Company	Revenues	Comments
Bosch (6041.DE) www.bosch.com	$33b	Automotive division $22b
Continental AG (CONB.BE) www.conti.de	$11b	Automotive Systems $4b
Dana Corporation (DCN) www.dana.com	$10b	$5b Automotive, Commercial Vehicle, Off-Highway
Delphi (DPH) www.delphi.com	$26b	67% of sales to GM
DENSO (DNZOF.PK) www.denso.co.jp/index-e.html	$18b	Japan's largest OEM
Eaton (ETN) www.eaton.com	$7b	$2.5b from automotive and truck groups
Johnson Controls (JCI) www.jci.com	$18b	$14b Automotive Systems Group
Lear Corp. (LEA) www.lear.com	$14b	Acquired United Technology Automotive in 1999
TRW (TRW) www.trw.com	$16b	Automotive $10b
Siemens VDO (Siemens, SI) www.siemensvdo.com	$6b	Formed from 2001 merger with VDO
Valeo SA (VLOFn.PA) www.valeo.com	$10b	Electrics and electronics 60% of sales
Visteon (VC) www.visteon.com	$18b	82% of sales to Ford

Go to www.DPRreferences.com for direct links to the indicated URLs and/or additional reference information.

Table 4. Automotive Semiconductors: Power

Company	Revenues	Website
Advanced Power Technology (APTI)*	$37m	www.advancedpower.com
Fairchild Semiconductor (FCS)*	$1b	www.fairchildsemi.com
Infineon (IFX)*	$6b	www.infineon.com
International Rectifier (IRF)*	$720m	www.irf.com
IXYS (SYXI)*	$83m	www.ixys.com
Microsemi (MSCC)*	$243m	www.microsemi.com
ON Semiconductor (ONNN)	$1b	www.onsemi.com
Toshiba (TSBAa.BE)	$41b	www.toshiba.com
Vishay Intertechnology (VSH)	$2b	www.vishay.com

*Companies on the DPR Power Panel and covered in previous issues.

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Finally, the fourth group comprises the manufacturers of power chips—the key components that add the power logic to the high-power electrical drive train. (See Table 4.) Just three companies—ON Semiconductor (ONNN), Vishay (VSH), and International Rectifier (IRF)—sell 90 percent of automotive powerchips. ON is an important supplier of automotive silicon, but is primarily (not exclusively) a manufacturer of analog, power-control integrated circuits, along with Intersil (ISIL), Linear (LLTC), and a few others. (ON Semiconductor, which is still 76 percent owned by Texas Pacific Group following a buyout from Motorola in 1999, has been beaten all but senseless on Wall Street.)

The ascendant powerchips in the high-power drive train comprise the much more important sector of this market, in our view. Sales into the North American automotive sector of high-power discrete powerchips are about $1.4 billion per year (globally, the number approaches $5 billion); these chips define a still relatively small subset of the total automotive silicon market, but the one poised to grow the most rapidly. The three dominant providers, who probably account for over half the automotive market, are International Rectifier, Fairchild Semiconductor (FCS) and Vishay. We've written previously about the first two of these companies before (*The Law of the Powercosm: Burn Silicon, April 2000; and The Tunable Powercosm, January 2001*). Alex Lidow, IRF's CEO, fully grasps the fundamental shift now underway in the automotive sector, just as the automotive engineers fully grasp the importance of his products. Lidow was a featured speaker at the aforementioned 2002 Convergence Conference, alongside the CEOs of (the much bigger) Delphi, DaimlerChrysler (DCX), Valeo (VLOFn.PA), and a Senior VP of Microsoft. Infineon, with its 2000 spin-out from Daimler, is a serious player, too, with the right pedigree in lower power automotive silicon. But it also has much larger parts of its business in memory and telecom and has suffered accordingly on Wall Street. Fairchild is substantially closer to a powerchip pure play. Fairchild's business is not yet heavily anchored in automotive applications, but Fairchild became one of the top powerchip companies in both technology and overall market share when it acquired Intersil's high-power powerchip business in 2001. We also like Microsemi (MSCC), which provides analog power amplifiers that are found behind the dash, driving LED and LCD displays and the like.

Vishay

Then there's the $1.6-billion (sales) Vishay—still 49 percent owned by Felix Zandman, the founder. Like his cross-country rival Alex Lidow at IRF, Zandman understands and is wholeheartedly pursuing the opportunities presented by the silicon car. About half of Vishay's business is in passive electronic components (high-reliability resistors, capacitors, and sensors); the other half is powerchips. Founded to manufacture high-performance passives for defense customers, Vishay has emerged as the market leader in total sales of chips and passives to automotive buyers. The silicon side of the company materialized when Zandman acquired Siliconix in 1998, and General Semiconductor in late 2001. Siliconix (still separately traded as SILI) was Daimler's semiconductor operation; General Semiconductor already had 20 percent of its business in the automotive sector when Zandman bought it. In 1998, Vishay also acquired Daimler's Telefunken, a leader in infrared sensors, along with power diodes, MOSFETs, and power ICs.

Siliconix, which now accounts for about $300 million of Vishay's sales, was the company that had invented the trenchFET version of the MOSFET. This architecture is very efficient and offers roughly four times the power density of a conventional MOSFET. It was originally developed for the cell phone and portable electronics markets to reduce the footprint occupied by the power electronics; Siliconix now licenses the trenchFET architecture to a number of other powerchip companies.

The evolution from military to automotive platforms was a natural one for Vishay. Military buyers require high-temperature, high-reliability, fault-tolerant components, and very high-quality control; so do car companies. Half of Vishay's sales are in datacom/telecom, which may explain why the company has been hammered of late in the markets. But unlike many other datacom companies, Vishay has always seen automotive as one of its main growth markets, and it already obtains roughly 20 percent of revenues from that sector. But its powerchips also land in tanks, submarines, aircraft, satellites, industrial machines, medical devices, and consumer goods.

Vishay also manages to capture a very respectable share of the collateral market for passive components in all these markets. As we've noted in previous issues (*Tantalum, Titanates, and Silicon, May 2002*), both the performance and the number of passives (capacitors in particular) have continued to rise with the proliferation of silicon logic. Sales of automotive passives are expected to rise even faster than sales of automotive silicon—passives will comprise a $3-billion automotive market in a few years, approaching half the forecasted $7-billion silicon market.

Vishay now supplies components that go into a very broad range of the car's current and emerging electronic infrastructure: air bags, alternators, head-light controls, ignition, suspension, speed control, steering, antilock braking systems, electronic system controls, navigation, and automatic seatbelt controls, among others. The company's expertise in high-power passives—precision, temperature-tolerant resistors and capacitors—has given Vishay an important edge in improving the thermal performance of its MOSFET packages, and importantly, a long and credible history in supplying the demanding Tier 1 automotive sector.

Beyond Cars

The rise of the electric drive train in cars defines a major opportunity in its own right. But the prospects are all the more promising because the digital power technologies that make it on the automotive platform will make it in industrial, medical, and consumer appliance applications as well. This is something altogether new in the modern era of energy technology—the emergence of major new families of cross-platform power components and modules, built mainly from silicon and software, that can readily be sold into defense, automotive, industrial, medical, and consumer markets, with all the vast economies of scope and scale that this implies.

The new technologies impose "digital" levels of precision and order on electricity, the ascendant "fuel" of our energy economy. More than 90 percent of the growth in U.S. energy demand since 1980 has been met by electricity. The nontransportation sector of our GDP (about 95 percent of the whole) already gets over half its energy from electricity. Today, about 60 percent of our GDP comes from industries and services that perceive and use electricity as their fuel; in 1950, the figure was only 20 percent. Some 60 percent of all new capital spending is on information-technology equipment, all of it powered by electricity. All the fastest growth sectors of the economy—information technology and telecom most notably—depend entirely on electricity for their fuel.

Electric power plants already account for about 40 percent of our total energy consumption, compared to (roughly) 30 percent each for transportation and heating. Electricity is progressively eating its way into the "heating" sector, most notably in the industrial context, where lasers, microwaves, and other forms of electrically generated photon power are now superseding conventional furnaces, ovens, dryers, and welders. Now, the same process is underway in the automotive sector.

From end to end, the energy economy is electrifying rapidly because power semiconductors have recently matured to the point where they can control electrons as quickly and efficiently and cheaply as logic semiconductors control bits. The same materials that switch microwatts of logic are now switching kilowatts and even megawatts of real power. They are also taking charge of the electron-to-photon conversions that allow so much new activity in solid-state lighting and photon heating.

Table 5. Additional Resources

Fischetti, Mark, "Why Not a 40-MPG SUV?" *Technology Review* (November 2002).

Gehm, Ryan, "Powering the Future," *Automotive Engineering International* (May 2002).

Ponticel and Buchholz, "Integration Hits Overdrive in Chassis Systems," *Automotive Engineering International* (May 2002).

Berger, Ivan, "Can You Trust Your Car?" *IEEE Spectrum* (April 2002).

Chan, C.C., "The State of the Art of Electric & Hybrid Vehicles," *Proceedings of the IEEE* (February 2002).

Kempton, Willett, et al., "Vehicle-to-Grid Power: Battery, Hybrid, and Fuel Cell Vehicles as Resources for Distributed Electric Power in California," California Air Resources Board and the California E.P.A. (June 2001).

Lidow, A., et al., "The Semiconductor Roadmap for Power Management in the New Milennium," *Proceedings of the IEEE* (June 2001).

Kassakian, John G., John M. Miller, and Norman Traub, "Automotive Electronics Power Up," *IEEE Spectrum* (May 2000).

Go to www.DPRreferences.com for direct links to the indicated URLs and/or additional reference information.

About half of the current demand for powerchips currently comes from the datacom/telecom sectors; industrial markets and consumer appliances account for perhaps another 10 percent each. The electrification of the automotive drive train over the next decade or two portends—roughly —a hundred-fold increase in demand for powerchips. No other sector, for any application, presents this magnitude of demand, or this growth rate. In time, Detroit will squeeze the margins out of this business, as it invariably does, but that will take many years; in the interim, some of the traditionally squeezed suppliers will prosper. For now, the manufacturers of automotive powerchips compete mainly against the far bulkier, slower, less reliable mechanical and hydraulic technologies that digital-electric power systems displace.

And while Detroit is getting around to squeezing them on prices, these same manufacturers will be migrating their technologies into a vast range of non-automotive applications, opened up to digital power technologies by the huge economies of scale—and concomitant price reductions—that the automotive sector provides. A few companies will emerge to dominate the growing power silicon market, just as comparable companies emerged to dominate logic silicon. The winners will almost certainly be the powerchip companies that combine first-rate powerchip technology with the experience, scale, and reliability standards that the automotive industry demands. Vishay certainly ranks in the center of the limited group of real contenders.

Peter Huber, Mark Mills
November 1, 2002

The Power Panel

For an explanation of the ascendant digital power technology for each of these companies, see the indicated issue of the DPR.

FEATURED COMPANY	DPR ISSUE	OTHER PLAYERS IN THE ANALYZED SPACE*
Advanced Power (APTI) www.advancedpower.com	12/00	Hitachi America (subs. HIT); Mitsubishi Semiconductor (subs. MIELY.PK); ON Semiconductor (ONNN); Philips Semiconductors (subs. PHG); Siliconix (SILI); STMicroelectronics (STM); Toshiba (TOSBF.PK)
American Superconductor (AMSC) www.amsuper.com	10/00	ABB (ABB); Intermagnetics General (IMGC); Waukesha Electric/SPX (subs. SPW)
Amkor Technology (AMKR) www.amkor.com	4/02	ChipPAC (CHPC); DPAC Technologies (DPAC)
Analog Devices (ADI) www.analog.com	8/01	Linear Technology (LLTC); Maxim Integrated (MXIM); STMicroelectronics (STM)
Analogic (ALOG) www.analogic.com	12/01	American Science & Engineering (ASE); Heimann Systems/Rheinmetall Group (subs. RNMBF.PK); InVision Technologies (INVN); L3 (LLL); Rapiscan/OSI Systems (subs. OSIS)
C&D Technologies (CHP) www.cdtechno.com	7/02	East Penn (pvt.); Enersys (pvt.); Exide (EXTDQ.OB)
Coherent (COHR) www.coherentinc.com	6/01	OSRAM Opto Semiconductors/subs. Osram (Siemens, SI, sole shareholder); Rofin-Sinar (RSTI)
Cree Inc. (CREE) www.cree.com	5/01	AXT (AXTI); Nichia Corporation (pvt.); Toyoda Gosei Optoelectronics Products/Toyoda Gosei (div. 7282.BE)
Danaher Corp. (DHR) www.danaher.com	2/02	Emerson Electric (EMR); GE-Fanuc (JV GE (GE) and Fanuc Ltd. (FANUF.PK)); Mitsubishi Electric Automation/Mitsubishi Electric (div. MIELY.PK); Siemens (SI)
Emerson (EMR) www.gotoemerson.com	6/00	American Power Conversion (APCC); Marconi (MONI.L); Toshiba (TOSBF.PK)
Fairchild Semiconductor (FCS) www.fairchildsemi.com	1/01	(See Advanced Power entry.)
FLIR Systems (FLIR) www.flir.com	1/02	DRS Technologies (DRS); Raytheon Commercial Infrared/Raytheon (subs. RTN); Wescam (WSC, Canada)
Harris Corp. (HRS) www.broadcast.harris.com	9/02	AI Acrodyne (ACRO); EMCEE Broadcast Products (ECIN); Itelco (pvt.); Thales (THS.L)
Infineon (IFX) www.infineon.com	12/00	(See Advanced Power entry.)
International Rectifier (IRF) www.irf.com	4/00	(See Advanced Power entry.)
Itron (ITRI) www.itron.com	10/02	ABB (ABB); Invensys (ISYS.L); Rockwell Automation (ROK); Schlumberger Sema/Schlumberger Ltd. (SLB); Siemens (SI)
IXYS (SYXI) www.ixys.com	4/00	(See Advanced Power entry.)
Kemet Corp. (KEM) www.kemet.com	5/02	AVX Corporation/Kyocera Group (AVX); EPCOS (EPC); NEC Corporation (NIPNY); TDK Corporation (TDK); Vishay (VSH)
Magnetek Inc. (MAG) www.magnetek.com	8/02	Ascom Energy Systems/Ascom (subs. ASCN, Switzerland); Astec/Emerson Electric (subs. EMR); Delta Electronics (2308, Taiwan); Tyco (TYC)
Maxwell Technologies (MXWL) www.maxwell.com	3/01	Cooper Electronic Technologies/Cooper Industries (div. CBE); NESS Capacitor/NESS Corp. (pvt.)
Microsemi (MSCC) www.microsemi.com	4/01	Semtech Corporation (SMTC); Zarlink Semiconductor (ZL)
Oceaneering Int'l. (OII) www.oceaneering.com	6/02	Alstom Schilling Robotics/ALSTOM (subs. ALS, France); Perry Slingsby Systems/Technip-Coflexip (subs. TKP); Stolt Offshore (SOSA); Subsea 7 (JV Halliburton (HAL) and DSND (DSNRF.PK))
Power-One (PWER) www.power-one.com	5/00	Artesyn Technologies (ATSN); Celestica (CLS); Lambda Electronics/Invensys (subs. ISYS.L); Tyco Electronics Power Systems/Tyco Electronics (div. TYC); Vicor (VICR)
Raytheon Co. (RTN) www.raytheon.com	10/01	BAE Systems (BA.L); Integrated Defense Technologies (IDE); Lockheed Martin (LMT); Northrop Grumman (NOC)
Rockwell Automation (ROK) www.rockwellautomation.com	9/01	Honeywell (HON); Invensys (ISYS.L); Mitsubishi Electric Automation/Mitsubishi Electric (div. MIELY.PK); Parker Hannifin (PH); Siemens (SI)
TRW Inc. (TRW)*** www.trw.com	1/01	Conexant (CNXT); Fujitsu (6702, Taiwan), Information & Electronic Warfare Systems/BAE Systems (div. BA.L); Northrop Grumman (NOC); RF Micro Devices (RFMD); Vitesse Semiconductor (VTSS)
Veeco Instruments (VECO)** www.veeco.com	7/02	Aixtron (AIX, Germany); Emcore (EMKR); FEI Company (FEIC); Riber (RIBE.LN); Thermo VG Semicon/Thermo Electron (subs. TMO)
Vishay Intertechnology (VSH) www.vishay.com	11/02	(See Advanced Power and Kemet entries.)
Wilson Greatbatch Technologies (GB) www.greatbatch.com	3/02	Eagle-Picher Industries (EGLP.PK); Ultralife Batteries (ULBI)

* Listed alphabetically; not a list of all public companies with similar or competing products; typically does not include private companies, except where they are large in both size and market share.

** Veeco and FEI Company announced a merger agreement on July 12, 2002; FEI will become a wholly owned subsidiary of Veeco, which will be renamed Veeco FEI and continue to trade as VECO.

*** Northrop Grumman and TRW announced a definitive merger agreement on July 1, 2002, in which NOC will acquire TRW.

Note: This table lists technologies in the Digital Power Paradigm and representative companies in the ascendant technologies. By no means are the technologies exclusive to these companies, nor does this represent a recomended portfolio. 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 interest in the companies.