the end of the m.e.?

They call this "convergence." Old lines are changing, or disappearing altogether. What it's doing under the hood is downright electrifying.

by Peter W. Huber and Mark P. Mills

The turf still divides up quite neatly. The electrical engineers move the light stuff—electrons, power, bits, and logic. The mechanical engineers do the heavy lifting; they move atoms. And, like it or not, the MEs still control most of the real estate.

Look at our cars. They're made of big heavy things that shake, bounce, and sway; they're propelled by pistons, shafts, gears, and belts; controlled by shafts, gears, valves, and hydraulic fluids. All the really important parts go click-click, bang-bang. The car is a 100 kW (peak) machine. The stuff that hums instead of clanking, the electric load, peaks at 2 kW.

Mechanical engineers control most of the rest of our energy economy, too. The United States consumes 100 quadrillion Btus, or quads, of raw thermal energy every year, in three broad sectors—electric power, transportation, and heat—with consumption split (roughly) 40-30-30 among the three. But electric power plants themselves are mainly thermomechanical: The furnaces, boilers, and turbines themselves consume over half of the fuel; only about 16 quads worth of mechanical energy actually get to the shafts that spin the generators that dispatch the gigawatt-hours.

Komatsu's 930E is a 2,000 kW truck. A 16-cylinder diesel engine drives a generator that powers electric motors on the wheels.

It doesn't have to be that way, and pretty soon it won't be. General Electric's 4,400-horsepower, diesel-electric GEVO-12 locomotive is powered by an enormous, diesel-fueled engine-driven generator; everything beyond is electric. Komatsu's 930E—a monster mining truck with 320-ton capacity—is propelled by a 2-megawatt Detroit diesel-electric generator. Everything else, right down to the 12-foot wheels, is driven electrically. Submarines have been largely all-electric for decades, and the surface ships now on the Navy's drawing boards are all-electric, from the propeller to the guns. Thermomechanical engines are still the prime movers on all of these platforms, but what they move is electricity. An on-board generator powers an all-electric drivetrain; an electric motor drives the propeller or wheels.

Electric drives are taking over because an electrical bus can convey far more power in much smaller, lighter conduits, and do it far more precisely and reliably, than even the best designed mechanical drivetrain. Indeed, on the key metrics of speed and power density, the electrical powertrain is about five orders of magnitude better. Electricity moves at close to the speed of light; all thermal and mechanical systems move at the speed of sound, or slower. It takes 10,000 driveshafts in 10,000 redlining Pontiacs to convey about as much power (1 gigawatt) as a single power plant dispatches down a few dozen high-voltage cables. By a very wide margin, electricity is indeed the fastest and densest form of power that has been tamed for ubiquitous use.

But precisely because it is so fast and dense, electricity is inherently difficult to control. Direct-drive electrical systems are fast all right, but they tend to jitter, overshoot, jerk out of control, and fall off the edge. The solution, historically, has been to get mechanical again—wrap the electric coils and magnets around heavy, inertial, and frictional components to get back to a simple and steady source of mechanical power—rotating a shaft, say—which can then be channeled through gears, belts, hydraulic fluids, and other arrays of click-click, bang-bang logic well before it reaches the final payload. Until recently, direct-drive electrical movers—systems in which the power stays electric right down to the very threshold of payload—have remained the exception, not the rule.

Power in Control

But big motors and their electric power supplies can now be built compact and precise enough to mimic the small muscles of a hand. A key breakthrough occurred in 1982, when Hans Becke and Carl Wheatley (both at RCA) were granted a patent for what is now called the insulated gate bipolar transistor. IGBTs are high-power semiconductor gates. They control kilowatts almost as efficiently as logic semiconductors control the picowatts that we call bits.

Sensors have also become sufficiently small, fast, and accurate to provide real-time feedback of what's happening at the payload. And cheap microprocessors are now readily available to make sense of it all, and to constantly recalculate how much power to dispatch to the drive to make it do exactly what's needed.

Supplied with a suitably shaped and amplified stream of power, a loudspeaker vibrates a diaphragm through a Beethoven symphony; do the same with a hundred kilowatts, and you can run a Pontiac. What's new now is that inexpensive semiconductors are available to provide the extraordinarily precise control of very large amounts of electric power, at very low cost, in very compact controllers.

The sidestick, being tested by Mercedes-Benz, is part of a fully computer-controlled car handling system of the possibly near future.

Because they move less material in the middle, direct-drive powertrains have far less inertia and friction; and because they are informed by very fast sensors controlled by computers they can react much faster to the outside world. Direct-drive motors can thus reach levels of precision that are completely unattainable with any conventional technology. With less weight in the powertrain, and fewer moving parts, direct-drives are also more robust. Pneumatic and hydraulic fluids leak, turn into molasses when they get cold, and are easily contaminated. Shafts, belts, and pulleys need lubricants, and get bent out of shape when they expand or contract. They corrode and need periodic maintenance. Electric wires don't.

The transformation is already well under way in the car's peripheral systems. The belts and pulleys that drive water and oil pumps, and radiator cooling fans, are giving way to electric motors. The best brakes are already electrohydraulic; all-electric brakes will follow. With electronic throttles, the gas pedal sends electrical instructions to a microprocessor that controls the fuel injection system electronically. Drive-by-wire electric power steering began appearing in production vehicles in 2001. Passive, reactive, energy-dissipating springs and shock absorbers are being displaced by an active array of powerful linear motors that move wheels vertically as needed to maintain traction beneath and a smooth ride above.

And electric actuators will displace the steel camshaft on every valved engine. Put each valve under precise, direct, digital-electric control, actuated independently by its own compact electric motor—open and close each valve as dictated by current engine temperature, terrain, load, and countless other variables—and, in effect, you continuously retune the engine for peak performance. Belts, shafts, and chains melt away. Everything shrinks, everything gets lighter, and every aspect of performance improves—dramatically.

To meet this steadily rising demand for electric power, car manufacturers are making the transition to a 42-volt grid to replace the existing 14-volt grid. Lower-voltage wires just can't convey large amounts of power efficiently. A new 42-volt industry standard emerged recently, and half of global automobile production will be on a 42-volt platform within the next decade or so.

Next-generation integrated high-power alternator/starter motors have already been incorporated in BMWs and Benzes, and in Ford and GM trucks; about half of all new cars will have them by 2010. These units will supply the car with abundant, efficiently generated electric power, in a much lighter package, that will provide a virtually instant engine start as well.

Cheap in the Gearbox

This will set the stage for the last big step—the one already taken in monster trucks: Silicon and electric power will knock out the entire gearbox, driveshaft, differential, and related hardware; electric drives power the motors that turn the wheels. Power chips now make it possible to build high-power motors the size of a coffee can, and prices are dropping fast. When such motors finally begin driving the wheels, the entire output of the engine will have to be converted immediately into electricity before it is distributed, used, or stored throughout the car. It will take heavy-duty wiring and substantial

silicon drives and electric motors to propel a hybrid-electric sport utility vehicle down a highway at 70 mph—but they'll be far smaller than the steel structures in today's powertrain. Cars will shed many hundreds of pounds, and every key aspect of performance will improve considerably.

As this process unfolds, the engineering focus will shift inexorably toward finding the most efficient means of generating electricity on-board. Trains and monster trucks both use big diesel generators. Hybrid cars on the road today burn gasoline, but it's the fuel cell that attracts the most attention from visionaries and critics of the internal combustion engine. Remarkably elegant in its basic operation, the fuel cell transforms fuel into electricity in a single step, completely bypassing the furnace, turbine, and generator. In this scenario, mechanical engineering ultimately surrenders its last major under-the-hood citadel to chemical engineers.

Much the same transformation is well under way in the factory. The 19th-century factory was powered by a single driveshaft spanning the length of the building; belts and chains delivered power to each individual work bay. That primary mechanical driveshaft gave way to electric power long ago, with motors powering the lathe, drill, or milling machine in each workstation. But, by and large, the motors still connect to shafts and belts and compressors. As in the car, mechanical systems still control the last few meters of the powertrain.

I, Sensitive Robot

The new industrial robots, however, are complex configurations of electric servo motors; the electric power now runs right to the final threshold of where the power is needed. Packed with sensors, the robots are now precise, sensitive, and far more compact than any mechanical alternative. They are also far more flexible—they now can be instantly reconfigured to perform new tasks through software alone, a dramatic advance over previous systems that required hours of manual rewiring.

At the same time, high-power lasers—built around another family of recently developed semiconductors—are rapidly taking over functions previously viewed as mechanical. At kilowatt and megawatt power levels, lasers don't move bits, they move material. They fuse powdered metals into finished parts, without any machining, cutting, or joining. They supply ultra-fine heating, soldering, drilling, cutting, and materials processing, with fantastic improvements in speed, precision, and efficiency. They create thermal pulses that can blast metals and other materials off a source and deposit them on a target to create entire new classes of material coatings. They move ink in printers—not just desktop devices, but also the mammoth machines used to produce newspapers. They solder optoelectronic chips without destroying the silicon real estate around them, and they supply unequaled precision in the bulk processing of workaday materials—heat treating, welding, polymer bonding, sintering, soldering, epoxy curing, and the hardening, abrading, and milling of surfaces.

Delphi has sold millions of its electric power steering units, which eliminate hoses, pump, and hydraulic fluid.

Mechanical systems can be remarkably clever—just look at how a high-end mechanical watch powers and times the movement of hands around the watch face. In engines and machines of every description, much of the mechanical engineering is still devoted to imposing a desired logic on the flow of power. Until quite recently, EEs themselves relied on at least semi-mechanical systems to choreograph and order the flow of electricity. The huge electromechanical switches that phone companies used to route calls until the 1960s set up circuits by reconfiguring tapestry-like arrays of small, electromechanical switches—thousands and thousands of them, clicking away, day and night. But the advent of the transistor—invented by Bell Labs—changed all that. Semiconductors now choreograph the flow of all-electric (or photonic) power through our watches and our phone lines.

Pushing semiconductors up the power curve took 20 years longer than it did to push them down. But it has now been done. And these fundamentally new technologies of "digital power" make possible an extraordinary new variety of compact, affordable, product-assembling, platform-moving, people- moving, and power-projecting systems that seem to be all but magical. They will inevitably infiltrate, capture, and transform the capital infrastructure of our entire energy economy—the trillions of dollars of hardware that convert heat into motion, motion into electricity, and ordinary electricity into highly ordered electron and photon power.

One might say that the age of mechanical engineering was launched by James Watt's steam engine in 1763, and propelled through its second century by Nikolaus Otto's 1876 invention of the spark-ignited petroleum engine. We are now at the dawn of the age of electrical engineering, not because we recently learned how to generate light-speed electrical power, but because we have now finally learned how to control it.

Peter W. Huber, a former mechanical engineering instructor at MIT, is a senior fellow of the Manhattan Institute. Mark P. Mills, a physicist, is a founding partner of a venture fund, Digital Power Capital. They are co-authors of The Bottomless Well (Basic Books, 2005) .