Green Means Go: FutureTruck Competition Brings Fuel Efficiency to Trucks/SUVs
by Lee Goldberg

Penn State FutureTruck Head-On

Greetings from Austin, Texas, the self-proclaimed "live music capital of the world," and what appears to be the highest per-capita concentration of tattoo parlors in any developed nation. And while the tattoos, blues, and booze that characterize Austin's 6th Street music district would be the destination of choice for most students: But a group of electrical and mechanical engineering majors seem just as excited to sit in a darkened conference room, boning up on hybrid vehicle technology. They have come to National Instruments' North Austin campus from 15 North American universities to attend one of several technical briefings they get as participants in the FutureTruck 2003 competition. http://www.futuretruck.org/

Conceived and managed by the U.S. Department of Energy's (DoE) Argonne National Labs, http://www.anl.gov/ the FutureTruck event is a bold initiative that challenges 15 university teams to re-engineer a conventional mid-sized truck or SUV into a lower emissions vehicle (LEV) with at least 25% better fuel economy. Contestants in the current two-year competition cycle have all been given identical 2002 Ford Explorers from Ford Motor Corp. as their baseline vehicle. They can modify their truck using virtually any technology, fuel, or construction technique, but must do their best to maintain as much as possible of the original performance, utility, safety, and affordability that the original truck delivered.

Last year, the teams ran their vehicles in the first of two performance "bake-offs" that factor in fuel efficiency, emissions, acceleration, handling, consumer acceptance, and off-road performance to determine the overall winner. Now a bit more than halfway through the two-year challenge, they are busy further modifying and refining their entries for the final competition this summer.

The Next Logical Step

Although Robert Larsen, Director of the Center for Transportation Research at Argonne Labs, laid the foundation for FutureTruck around 15 years ago, the recent concern over America's dependence on a high percentage of imported petroleum, the pressure to require tailpipe emissions from SUVs be as clean as those from automobiles plus the possible specter of global warming makes the program even more timely today. This, coupled with the fact that over 50% of US new vehicle sales are either light trucks or SUVs means that the technologies the students are using could play a critical role in reducing both our fuel consumption and cleaning our air.

The innovative fuel-saving technologies being pioneered by Ford, GM, Honda, Toyota, and others that will be showcased at FutureTruck are essential for improving the economy of both cars and heavier vehicles. Pat Ford, Project Manager of the FutureTruck program at Ford Motor (no relation to the company's founding family), explained that the incremental improvements being made in conventional cars and trucks were approaching their limits.

Ford's Pat Ford, "Conventional fuel-saving technologies are approaching their limits. Hybrid technologies are the next step."

Larsen pointed out that over the years manufacturers have squeezed most of the practical savings possible from reduction of aerodynamic drag. And while vehicles can be made a bit lighter, most of the "low hanging fruit" is already picked. "There are just darned few cost-effective materials that are light and strong enough to replace steel in most structural parts," he sighed. Pat Ford added that he expects to see another 5%-10% reduction in vehicle mass with aluminum and composites in the next 5 years, but not much more.

By pushing traditional design practices to their limits most officials at the FutureTruck conference expect the industry to coax 5%-10% mileage gains from a conventional five-passenger Taurus-class vehicle. From that point most future energy savings will have to come from so-called exotic technologies, such as fuel cells and hybrid-electric propulsion systems.

While they still rely on a small conventional internal combustion engine (ICE), hybrid vehicles also have an electric drive subsystem to provide bursts of added power for acceleration and climbing hills. This allows them to use a smaller, lighter, gasoline engine that can easily maintain the car at cruise speeds. Surplus engine power and energy recovered from dynamic braking are turned back into electricity and pumped back into the on-board battery for the next hill or stoplight.

Depending upon the specifics of the hybrid technology the manufacturers add to the equation, they expect to see a 25%-50% improvement in a vehicle's overall fuel efficiency, with the most gains in stop-and-go traffic. Roughly 50% of the savings will be realized from engine downsizing, while 20-30% will come from regenerative energy capture. The rest of the efficiency gains will come from sophisticated engine control features, such as allowing the engine to run within a tighter RPM range and letting it turn off and on at stoplights and other low-demand situations.

Improved control strategies for ICEs may boost efficiency even further. Larsen explained that today's automotive electronics afford excellent control over engine spark and fuel, but electronic valve actuation is still under development. "Once the intake and exhaust are under reliable computer control," he said, "We'll be able to manage the combustion process even more tightly. And more control," he grinned, "Means more efficiency."

A Potpourri Of Technologies

The once-stock trucks have evolved to incorporate an interesting cross-section of clean-burning, high-efficiency propulsion systems. While most of the trucks still run ICEs under their hoods, the power plants replacing the original 4.0-liter V-6 range from an Ethanol-burning (85% Ethanol/15% gasoline) 4-cylinder, 1.8-liter turbocharged Mazda unit, to an assortment of compact diesel engines outfitted with experimental catalytic soot traps. Most of the diesels also burn a 35/65 "bio-diesel" blend of soybean-derived and petroleum-based fuel.

The design of the hybrid-electric elements that augment the smaller engine's performance also vary wildly, with teams placing engines ahead of, behind, and even in parallel with the transmission. At least two teams have chosen a "through-the-road" hybrid system where the "gas" engine does the majority of the heavy lifting through the rear wheels while a completely separate electric drive on the front wheels provides additional boost and braking. Unfortunately, the two schools that developed hydrogen fuel cells have had to move on to different technologies when their fuel cell supplier was acquired by General Electric last year and dropped out of the program.

To manage all the additional systems, these vehicles pack a bunch of extra electronics. While a production hybrid vehicle will use purpose-built automotive control modules, the students' prototypes make heavy use of data acquisition and control modules supplied by National Instruments (NI) as part of its sponsorship role. Peter Zogas, vice president of sales at National Instruments, explained how NI's ruggedized PC-based instrumentation modules provide a "quick-and-dirty" way to develop and implement control algorithms for vehicle management functions. “Typical tasks might include a drive-by-wire throttle that smoothly blends electric and gasoline power, or managing energy flow during regenerative braking,” he said.

In a different configuration the same module can be used to perform most of the elaborate monitoring and analysis tasks required to understand the overall performance of the vehicles, and their subsystems. Since much of the scoring is based on efficiency and performance each team will outfit its vehicle with the electronics necessary to measure its energy consumption, speed and acceleration and compare it to environmental and the road conditions. By correlating this against distance traveled - derived by GPS and augmented by inputs from the odometer and wheel position - the teams and the judges can get a detailed picture of how the car uses its energy under varying road conditions.

Under The Hood

Since facts and figures don’t mean much unless they translate into a vehicle that’s easy and fun to drive, my pedal foot was just itching to get hold of one of the FutureTruck machines. Happily, our hosts were more than happy to oblige. I was introduced to Paul Minear, and Jon Weidner, a pair of EE majors at Penn State, who had brought their team’s hybrid diesel-electric Explorer out to Austin with them.

FutureTruck contestants Paul Minear, Jon Weidner, pose with Penn State’s truck and mascot

At first glance, the Penn State entry looks pretty much like a stock Explorer…well pretty much stock, as long as you ignore the dozen-odd sponsors' stickers plastered all over its hood and hindquarters. The resemblance begins to fade quickly as soon as you pop the hood and find a cute little 4-cylinder 2.5-liter Detroit Diesel unit tucked in where the gas-burning 4-liter V-6 used to be. This, a few dozen yards of added plumbing, several mysterious boxes of electronics, and some non-Ford cable bundles that are obviously designed to carry high amperages all give you the idea that this truck has seen some *serious* modification.

A brief crawl under Penn State's creation reveals the electric side of the drivetrain – a 37-kW ac induction motor originally used as the primary drive in a Solectria Force www.solectria.com electric car. It's coupled in parallel with the output shaft of the truck's 5-speed transmission, just ahead of the transfer case.

Under the hood, a 2.5-liter diesel, and a 37-kW electric motor

Most of the Explorer's stock interior has been left intact, with the lead-acid battery pack tucked neatly in the rear of the vehicle. One might never suspect the big changes lurking behind the firewall, except for a few non-stock switches on the dash, and a large heap of sensing and control modules that have been shoehorned between the first two passenger seats. While rather messy-looking, the electronics are well-positioned to make the frequent tweaking and reprogramming with new software uploads fast and easy. A large LCD mounted above the electronics allows the "flight engineers" in the back seat to call up various monitoring and diagnostic screens, as well as make real-time tweaks to the control algorithms that govern the behavior of the electrical systems.

Inside the prototype - several computers, loose wires, and fuzzy dice

The software is one of the things still undergoing significant changes as the car approaches its final configuration for the 2003 competition this spring. While all the functions, such as transitions between pure diesel and diesel-electric propulsion and regenerative braking are functioning, the algorithms are still being refined to yield the best efficiency, and the best possible driver experience.

Green Means Go!

And speaking of driver experience, I was able to talk Jon and Paul into letting me take the left seat in their hand-built vehicle. I slid into the leather bucket seat, adjusted the mirrors, turned the key, and was rewarded with the burbling rattle of the sweet little Detroit mill at idle. Unlike some hybrids (such as the Toyota Prius) the Penn Truck's simpler parallel drivetrain usually requires the petro-engine to be turning in order to be driven. My preflight instructions were pretty simple - don't touch the extra (non-stock) switches embedded in the dashboard, try to keep the engine below 3000 RPM, and don't crash into anything.

Easing in the clutch with about one-third-throttle produced a pleasant, beefy push into my seat as we pulled away from the curb. At this point, Paul told me, we were still under straight diesel power, but the low-end torque characteristics gave it a very satisfying punch. Once underway the diesel's perking noises faded and my experience of driving around the grounds of the National Instruments' campus became indistinguishable from a conventional SUV. I still wanted to see what the truck would do when pressed, so I located a patch of straight road and punched the throttle down.

With the truck in second gear and the pedal to the floor, there was a very slight hesitation as the diesel adjusted to the load and the electric drive system decided what to do. Once the systems made up their mind the Explorer hunkered down and began to do its stuff. The pull from 20 mph was quite brisk and continued to glue my butt into the seat as we shifted to third gear at around 40 mph, just before we ran out of straight road. Although I have not driven a stock Explorer to compare it to, the 4-cylinder hybrid felt very much like the other V-6-powered light trucks and SUVs I've been in. Jon said that their truck actually accelerates slightly better than with the original equipment, and I believe him.

The author at the wheel, "I've gotta get me one of these!"

Deceleration and braking were smooth and effective, hauling us down to a reasonable speed before the truck encountered the guard rail at the curve that loomed in the windshield. The brake action was so seamless that I had to take Jon's word that the regenerative braking system was actually taking much of the kinetic energy and putting it back into the batteries. Jon also explained that the slight hesitation I felt was a shortcoming of the control system that read throttle position and blended the electric power into the drivetrain. The original system they developed only reads throttle position in coarse increments of around 25%, causing small, but noticeable, surges and lags. I'm sure that well before the Penn State Explorer arrives for its final competition in Detroit this June, the new throttle hardware (and matching software) will have sufficient granularity to completely mask the slight hesitation from the diesel and provide a very seamless blending between the two power systems.

Bad News/Good News

These, and other changes to the vehicle, should make it perform as well, or better, than an out-of-the-box Explorer under most conditions. Extremely long uphill pulls with a large trailer in tow, or highly-demanding off-road conditions will eventually deplete the reserves in the electric drive system faster than they can be replaced, and force the car to rely solely on diesel power. But 90% or more of the folks who drive these kinds of trucks will rarely, or never, encounter those conditions.

For those that need full power all the time they can keep their 12-15-mpg trucks. The rest of us may soon be able to enjoy the 25-50% increase in fuel economy that hybrid trucks are expected to deliver. While the Penn State Explorer has only been able to demonstrate fuel economy roughly equivalent to the 15 mpg that the unmodified control vehicle delivered on the FutureTruck test course, everyone agrees the future looks bright. Last year, during the 2002 competition (when the trucks were not modified or fine-tuned), seven of the 15 vehicles were able to equal or better the stock SUV mileage. The best mileage for 2002 was delivered by the University of Wisconsin's diesel-electric hybrid, which turned in an impressive 21.85 mpg (Vs. the 15.06 for the control vehicle), a 45% improvement.

All the trucks are expected to do much better when they meet in Detroit in June, after a full year to refine their designs. For Paul and John, this will mean spending the next several months installing and testing software tweaks, and making some last-minute reductions in structural and rotating mass, with perhaps a few last-minute surprises.

We pulled into the parking space and I reluctantly turned off the engine. This had been fun and I was already trying to imagine how much a "civilian" version of such a FutureTruck vehicle would cost, and when it would be available. Noticing the wistful look in my eye, Pat Ford told me that Ford was preparing to bring a hybrid version of its Escape mini-SUV to market some time in 2003. http://www.hybridford.com/index.asp He said that Ford's goal is to be able to offer it for sales at only a slight premium over the cost of a conventional Escape. It's expected to deliver 35-40 mpg in city driving, and 29-30 mpg on the highway.

Besides giving environmentally-minded consumers their first chance to buy American, the hybrid Escape may signal the start of a growing market for the sophisticated control electronics that make the dual-system vehicle operate smoothly and efficiently. This in turn would mean more opportunities and jobs for electrical engineers and technicians who design, manufacture, and support these vehicles, and their successors.

While its smaller size may not make it useful to some current truck owners, it should address a good percentage of the public who want a sporty vehicle with a bit more capacity and capability than a conventional sedan. In any case, it will still be a good start towards improving the fuel efficiency of the American fleet.

The hybrid Escape represents the fruit of many years of research by Ford, but it also borrows ideas from university research and earlier student engineering competitions like FutureTruck. In time, we can expect to see the cars and trucks we drive reflecting the lessons learned by John, Paul, and their colleagues as they learn to turn their engineering dreams into practical realities. And in doing so they create a better world for all of us.

For more information on the FutureTruck competition, and its associated events, point you browser to http://www.futuretruck.org/, or contact Kristen De La Rosa, Project Manager Argonne National Laboratory 2206 East 22nd St., Austin, TX 78722
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