Powertrain
Ford's all-new 6.7-L V8 raises the diesel-engineering bar

Diesel engine OEMs, here comes your new medium-duty benchmark.

**Ford** Motor Co. is completing validation of its 6.7-L V8, due to enter production late next year as an option for 2011 Super-Duty trucks. The all-new V8 is the first Ford diesel engine to be developed entirely in house. It is also the first to be certified to operate on 20% biofuel (B20) and the first to comply with U.S. EPA 2010 emissions standards that require an 80% reduction in NOx.

The engine is a showcase of clever packaging, combustion control, and robust design. Code-named “Scorpion” during development, the “Six Seven” as it is now known features the following key technologies:

- Compacted graphite-iron (CGI) cylinder block
- Aluminum cylinder heads with dual coolant jackets
- Inboard-facing exhaust ports with outboard-facing intake ports
- A single-sequential turbocharger mounted within the V of the block
- Piezoelectric fuel injectors operating at 30,000 psi (2070 bar) and capable of five injections per combustion cycle
- Ford-patented software controls for mixing the urea fluid in the selective catalytic reduction (SCR) exhaust aftertreatment system. This will be the first North America-designed diesel to employ SCR.

The engine’s power and torque ratings will be announced later. Output and fuel efficiency are expected to be significantly greater than those of the current 6.4-L PowerStroke diesel V8 sourced from **Navistar International** and should give the SuperDuty range class-leading payload and towing credentials, according to Lead Engineer Adam Grygiel.

Besides being extremely package-efficient for its size, a result of the intake system design, the new V8 also will set new class standards in NVH attenuation. **Aei** was among the first media invited to background discussions with Grygiel’s team and to hear the engine demonstrated in an F-450 flatbed truck. The sound levels we witnessed were stunningly low and mechanical clatter virtually absent. This was all the more impressive because the truck was running inside a huge, echoing garage and was not fitted with an underhood noise blanket.

Indeed, the new V8’s sound profile is so subdued that Ford engineers say traditional acoustic blankets will not be fitted to production vehicles using this diesel. Likewise, sound levels at the tailpipe from idle through middle-range rpm are on par with some large-displacement gasoline engines.

“The question of how quiet do we make it was an ongoing debate among the development team,” noted NVH engineer Scott DeRaad. His group was on the critical path of the program since its genesis in 2006.
Development kicks off

The new diesel is an important power unit for Ford. Sixty percent of the company's heavy-duty F-250/350 pickup trucks are purchased with the PowerStroke diesel. The company has produced more than 3.5 million of these vehicles in the last two decades.

According to Gryglak, a 20-year veteran of Ford Powertrain engineering, the opportunity to develop a clean-sheet diesel was "rare and exciting" for the team—"something a powertrain engineer might get one chance to do in their career," he noted.

Combustion system development began in the early 2000s as a Ford Research and Advanced Powertrain project. But by mid-2006 Ford management decided to rapidly accelerate the work toward a full-scale engine program. This was due in large part to the disintegration of its long-time PowerStroke supply relationship with Navistar.

Production of the Navistar-built Ford V8s ends Dec. 31.

After development of the new V8 began, Ford also entered discussions with General Motors about a potential collaboration on diesel V8 engines. GM had its 6.6-L Duramax for heavy-duty pickups and was well along in developing an all-new 4.5-L unit for U.S. light-duty applications. Ford had developed its own 4.4-L light-duty V8 (current status is on hold) in addition to the 6.7-L V8 program.

According to engineers familiar with the talks, it was

Lead Engineer Adam Gryglak has worked on diesels for 9 of his 20 years at Ford Powertrain. The new "Six Seven" is his first clean-sheet engine program.
thought the two companies might create noncompetitive synergies by replicating their successful joint six-speed automatic transmission program, which has helped each achieve significant cost savings.

GM's 4.5-L design also featured inboard-facing exhaust, a package solution proven on various historic gasoline V8s including Cadillac flatheads, Ford's Indianapolis-winning V8 of the 1960s, and the current BMW twin-turbo gasoline V8. GM had also settled on a CGI block for its diesel, with a single turbocharger nestled in the valley. It differed in having a DOHC valve-train and integral exhaust manifolds, while Ford chose a more compact OHV design and bolt-on manifolds.

Preliminary discussions between Ford and GM centered on basic package surfaces. But collaboration wasn't to be. Both sides ultimately decided to pursue independent development paths. And earlier this year, GM killed its 4.5-L diesel program which was slated for 2010 production.

When the 6.7 program was approved in late 2007, Ford heavily leveraged its European diesel engineering expertise, particularly in combustion-chamber design, explained Gryglak. He said the development team assembled in Dearborn included staff from Research, Advanced Powertrain, and Navistar applications veterans. The four lead manufacturing engineers from Ford U.K. were co-located with their design counterparts to bring experience from the European Puma and Lion diesel programs.

### Innovation throughout

The foundation of the new architecture is the deep-skirted CGI block. Its material properties—CGI is approximately twice as strong as gray iron—allow for thinner internal walls and major bulkheads, which help save mass. The block is cast in Brazil by Tupy SA and features cross-bolted main bearing caps for strength. The 6.7-L is designed for a 300,000-mile (483,000-km) duty cycle without major maintenance, noted Lead Durability Engineer Ed Waszczenko. He added that the dynamometer test schedule calls for 75 million cycles between idle and wide-open throttle. Among the many design changes to reciprocating parts aimed at boosting durability are the connecting rods. They are more robust overall and now include small-end bushings, the wrist pins in the Navistar V8 fit directly on the rod.

Bore and stroke measure 99 x 108 mm (3.9 x 4.3 in), respectively. According to Gryglak, the V8's overall design "has displacement headroom and can also accommodate smaller-displacement versions."

The aluminum heads with four valves per cylinder are responsible for most of the new diesel's 160 lb (73 kg) weight savings, compared with the old iron-head 6.4-L V8. The heads are cast by Nemak, while Ford handles final machining at its Chihuahua, Mexico, engine plant, where the 6.7 is assembled.

The heads' inboard-facing exhaust ports feed the Honeywell turbocharger situated in the V. Compared with conventional outside-facing ports, this tight plumbing helps reduce the exhaust system's total volume by 50%, optimizing heat transfer. It also greatly aids throttle response by helping the turbo spool up faster.

The heads are fixed to the block by six bolts (two more than on the 6.4-L) to spread the clamping load more evenly. The heads incorporate dual water jackets, which provide internal manifolding. The engine uses two coolant pumps. One is for engine thermal management, and the other handles the air-to-water charge-air cooler and EGR cooling system.

The heads are designed to handle the V8's 2600-psi (179-bar) cylinder pressures. Compression ratio is 16.2:1.

Ford claims an industry first with its application of the single-sequential Honeywell turbocharger, formerly called SST and now dubbed "Dual Boost." It features a single turbine impeller driving a pair of compressor wheels. This arrangement functions like a small-displacement turbo combined with a large-displacement unit, giving immediate response at both low and high engine rpm and smoother response across the operating range.

In addition, variable-pitch impeller vanes are actuated by means of new turbine-nozzle technology. The choice of air-to-water charge cooling yields half the system volume of an air-to-air cooler, with a
significant reduction in charge temperature—50°C (122°F) compared to 90°C (194°F), said Gryglak.

The turbocharger mounting is one of the many holistic design elements that make the 6.7-L diesel’s NVH performance so impressive. The turbo housing mounts solidly on a patented pedestal situated low in the cylinder valley.

The Bosch fuel injection system also helps reduce noise by not using post-injection events during idling, although Gryglak admits that the piezo-type injectors are inherently noisier than solenoid-actuated types. The trade-off was improved engine-out emissions, he said.

Asserted NVH boss DeRaad: “Fuel system flexibility, the stiffer block, and good fundamental core engine design were the main drivers for NVH reduction.” He explained that very detailed analysis was lavished on the engine’s timing gears, with experts from Ford’s automatic transmission group enlisted to help optimize tooth pitch, lash, and helix angles to minimize gear noise.

Other NVH actions include the use of Helmholtz resonators in the intake manifold and clean-air tube, and acoustic covers lined with melamine foam are mounted on the rocker covers to reduce high-frequency sounds.

Ford IP is key to aftertreatment
According to emissions engineer Chris Oberski, the 6.7-L development team chose SCR as the primary NOx-control technology because it does not require periodic rich operation—a fuel-efficiency benefit.

The Honeywell single-sequential “Dual Boost” turbocharger is mounted within the valley of the V8’s cylinder block to create a smaller overall package, optimize thermal management, and improve turbo response.

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Energy
Move to Li-ion requires many technical changes

Battery technologies recently got a huge shot in the arm when federal grants were handed out. This portion of the economic stimulus package aims to make lithium-ion (Li-ion) the technical base for electrified vehicles, but it also underscores the many technical changes automakers and their suppliers must make.

Battery companies got the bulk of $2.4 billion in grant monies given to transportation companies by the U.S. Department of Energy in August. To name a few, A123Systems got $249 million, BASF collected $24.6 million, EnerDel Inc. received $118.5 million, and Johnson Controls was given $299 million. Many others got funding designed to build an infrastructure for hybrid and electric drive vehicles.

The moves mark a significant advance in the move to electrified vehicles, but the transition also means that engineers will have to make a number of changes in their control systems. Li-ion brings significant benefits over the nickel metal-hydride (NiMH) batteries now used in hybrids.

Foremost among them is the ability to deliver more power from smaller batteries. Most automakers will leverage that to shrink the size of battery packs.

"The nice thing about lithium is that you can get smaller batteries," said Larry Nitz, General Motors Product Marketing Engineer for Hybrid Powertrains. "We won't use lithium to get more power."

"Li-ion batteries will quickly degrade when charged to 100% full capacity or discharged to 0% state-of-charge," said Greg Zimmer, Product Marketing Engineer...