APBF-DEC

Quarterly Update

Advanced Petroleum-Based Fuels–
Diesel Emissions Control (APBF-DEC) Project

#6, Summer 2002

Setup & Calibration Phase Nears Completion

The hardware setup phase of the APBF-DEC's five projects is nearing completion and several projects are showing preliminary results that are currently being analyzed. Vehicle and engine systems have been set up at the laboratories where the projects are being conducted. Prior to collecting data on systems performance and emissions, engines and emission control devices were set up in test cells. Fuels were delivered to the laboratories for use in the tests. They include a base fuel containing less than 3 parts per million (ppm) sulfur (S) and special test fuels. The special test fuels include the base fuel "doped" to levels required for the tests (8- and 15-ppm S), and an ultra-low sulfur refinery fuel (BP15). Test designs were prepared and the data analysis team developed a format for recording data consistently. The data analysis team worked with the teams overseeing the projects involving lubricant reformulation, selective catalytic reduction (SCR)/diesel particle filter (DPF) technologies, and nitrogen oxides (NO_x) adsorber/DPF technologies to develop consistent test protocols.

Site visits to the four test laboratories were conducted during April, May, and June. Members of the APBF-DEC Steering Committee and working groups share information about the five projects during regularly scheduled conference calls and via a technical Web site. Presentations about the APBF-DEC projects were given at several spring conferences, including the Society of Automotive Engineers (SAE) Future Car Congress in June. Project leaders and subcontractors will provide progress reports at a joint technical meeting in Washington, D.C., October 9-10. Summaries of those presentations will be provided in the Fall APBF-DEC Quarterly Update.

Following are summaries of progress through July 2002. Companies and associations providing engines, systems, and support; objectives for each project; and initial setup steps were described in previous issues of the *APBF-DEC Quarterly Update,* which are posted on the Web site (http://www.ott.doe.gov/apbf.shtml).

Selective catalytic reduction/diesel particle filter (SCR/DPF) technologies, fuels, engines– Southwest Research Institute (SwRI), San Antonio, TX, testing laboratory, test bed: Caterpillar C-12 engine.

The calibration and optimization of System A has been completed. System A is a combination of a DPF and urea SCR catalyst. Two different systems are being tested, as described in the following steps.

First, the low-pressure-loop exhaust gas recirculation (EGR) and the DPF were installed, so the engine-out NO_x and PM were reduced substantially. Second, the System A SCR catalyst was installed and calibrated to optimize NO_x reductions.

SCR/DPF. The selective catalytic reduction technology (SCR) is an emissions reduction device that, combined with a diesel particle filter (DPF) and advanced fuel formulations, has the potential to reduce regulated, unregulated, and toxic emissions. Two types of SCRs and DPFs are being evaluated.

The purpose of the test is to demonstrate the low diesel emissions possible by using the SCR/DPF and to evaluate the sensitivity of emission controls to fuel variables.

BACKGROUND
APBF-DEC is an industry/ government project to identify and evaluate (1) the optimal combinations of low-sulfur diesel fuels, lubricants, diesel engines, and emission control systems to meet projected emission standards for the 2001 to 2010 time period and (2) properties of fuels and vehicle systems that could lead to even lower emissions beyond 2010. Sulfur in the fuel is known to interfere with the functioning of most emission control technologies and has been implicated as a possible factor in the formation of ultrafine particulate matter (PM). A systems approach is being used, i.e., simultaneously investigating fuels, lubricants, engines, and emission control systems.

A government/industry steering committee and working groups are guiding the APBF-DEC project. Funding for the project is expected to total $33 million, including $19.3 million in cash ($12 million from the government) and $14 million in in-kind contributions. The project is managed by DOE's National Renewable Energy Laboratory (NREL). Information about the APBF-DEC project is posted at: http://www.ott.doe.gov/apbf.shtml.

APBF-DEC is the successor to the Diesel Emissions Control-Sulfur Effects (DECSE) project. Its objective was to determine the impact of fuel sulfur levels on the performance and short-term durability of emission control systems, which could lower emissions of NO_x and PM from diesel-powered vehicles in the years 2002 to 2004.

In February 2002, the final *DECSE Summary of Reports* was published. This publication briefly describes DECSE's final results. The summary and other DECSE publications and technical reports are available at: http://www.ott.-doe.gov/decse/.

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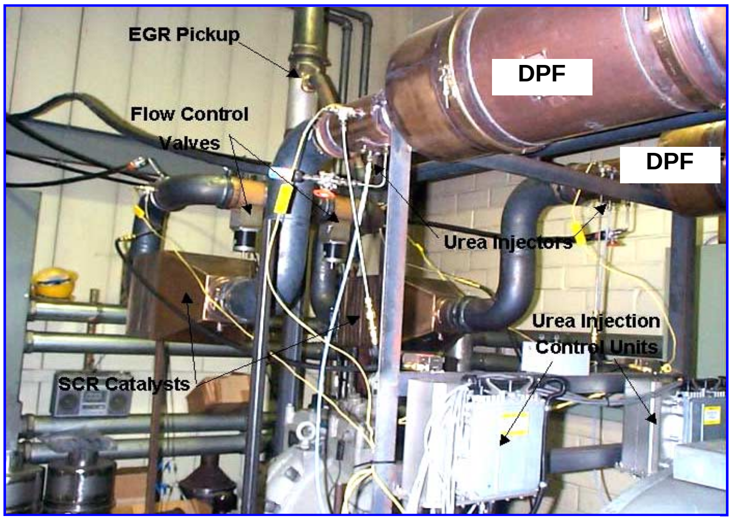

An SCR/DPF system installed in an engine test cell at SwRI.

The EGR system reduced the engine-out NO_x by about 50 percent. With the installed SCR catalyst and urea injection system, efforts were directed at calibrating and optimizing tailpipe NO_x reductions to reach the target 0.20g/bhp-hr, which is the U.S. EPA's regulatory standard beginning in 2007. Several iterations of steady-state calibrations were performed and NO_x reductions on the steady-state European test cycle were substantial.

Attempts to calibrate for the U.S. EPA transient cycle (FTP) found that NO_x reduction suffered when the exhaust temperature was too low for satisfactory catalyst performance. Also the urea injectors needed a lower urea* flow threshold to reliably provide lower urea injection flow when needed. To remedy the temperature problem, the exhaust system was shortened and insulation was added. The urea injectors were modified and recalibrated by Bosch so the injectors would have a lower minimum injection rate. After these changes were made, the system calibration was again optimized, and the results for NO_x reduction were encouraging. The reductions are being achieved with a fuel penalty of only 3 to 4 percent, with little ammonia slip and little NO_2 production.

System A will now undergo the series of tests with fuels of different sulfur levels and the BP15 refinery fuel. Tests for toxic and unregulated emissions will also be performed. Then System A will be transferred to another test cell to begin the durability test. System B will begin the emissions calibration process.

NO_x adsorber/diesel particle filter (DPF) technologies, fuels, engines –

Three projects testing NO_x adsorber/DPF technologies are currently underway at three laboratories, using three different engines to assess the effects of fuel composition on emission control systems' performance. Similar tasks are underway for the three projects: measure regulated and unregulated engine-out baseline emissions and fuel consumption; evaluate the system's performance versus the fuel sulfur level over transient and steady-state cycles; determine the best emission control systems (ECS) and sulfur levels for testing; and examine the effects of fuel properties, other than sulfur content, on regeneration and desulfurization strategies.

> **NO_x Adsorber/DPF.** The NO_x adsorber catalyst is a flow-through exhaust emissions control device with the potential to significantly reduce nitrogen oxides (NO_x), hydrocarbon (HC), and carbon monoxide (CO) emissions in the exhaust from diesel engines. When combined with a DPF, the system also can oxidize the diesel particulate matter (PM) and other unregulated emissions.
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> The purpose of these tests is to demonstrate the potential of low-sulfur fuel to enable achievement of stringent emission reductions from diesel engines using a system that includes the engine, fuel, NO_x adsorber, DPF, and thermal management technologies.

- **FEV Engine Technology, Inc., Auburn Hills, MI, test bed: a light-duty passenger car** (Audi A4 Avant with a 1.9L TDI engine). The project received the hardware (including all four engines and the first set of ECS components), installed two engines in the test cells, and calibrated the engines to minimize the engine-out NO_x levels. The third engine will be installed in the transient test cell this month. Engine number four has been installed in the Audi A4 Avant vehicle. In addition, the electronic control unit (ECU) bypass system has been completed and installed in the test cell.

Final preparations for the testing phase are underway, including completion of emissions sampling protocols and the data collection plan, integration of the engines and vehicles, cold-start testing and resolution of rapid warm-up issues, mapping and testing the EGR, and testing the engine management software. Comparison tests between the engines in test cells #1 and #2 are also being conducted. The laboratory has received the first sets of ECS components for the project. Engine control strategies for these devices will be developed and optimized, beginning in August and continuing through December.

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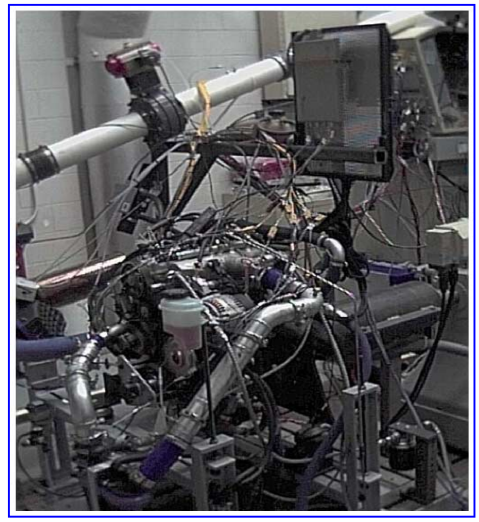
* Urea is considered to be a stable and safely transportable means of providing ammonia to SCR catalysts. It is an aqueous solution that, when heated, can produce ammonia that can react to reduce NO_x to elemental nitrogen in an SCR device. The final report about the urea infrastructure (*Selective Catalytic Reduction Urea Infrastructure Study*) is available on the APBF-DEC section of the OTT Web site (http://www.ott.doe.gov/apbf.shtml).

Two new 3,000-gallon tanks at FEV's expanded fuel farm have received shipments of 0.6- and 15-ppm S fuel. The 8-ppm S fuel and the BP15 refinery fuel will be stored in drums. The 15-ppm S fuel will be used for the extended durability testing phase of the project. Baseline engine-out testing is expected to begin in September, using 8- or 15-ppm S, and BP15 refinery fuel. The baseline testing over transient test cycles is to be completed in October.

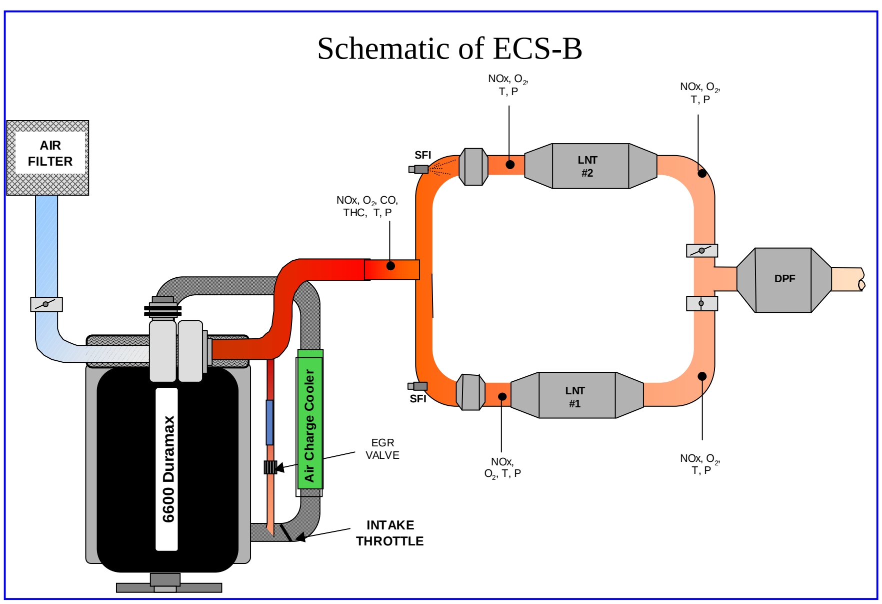


One of the four engines in the NOx adsorber/DPF light-duty passenger car project is shown in the test cell at FEV.

At the technical meeting held at FEV's Auburn Hills, MI, facilities in June, criteria for NO_x adsorber desulfurization and DPF regeneration events were discussed. The exhaust system was shortened and the smoke meter was removed, which resulted in a higher exhaust temperature as confirmed by repeated transient tests. The catalyst aging cycle and a lean rich timing for regenerating the NO_x adsorbers are also being discussed. FEV is working with the Oak Ridge National Laboratory (ORNL) on setups of the filters and impingers to collect samples of unregulated emissions. Several tasks are planned for the coming months: investigating a rapid catalyst warm-up and the possibility of modifying the EGR cooling system; modifying the exhaust systems; and refining the baseline calibration of the vehicle's engine.

- **SwRI, San Antonio, TX, test bed: a light-duty truck/SUV** (a 2500 series Chevrolet Silverado, with a Duramax 6.6 liter [L] engine). In addition to the base fuel of 0.6-ppm S for development work, this project will use the 8- and 15-ppm S fuels for the majority of the evaluation testing and use the BP15 fuel for the unregulated emissions and the 30-ppm S fuel for limited excursion testing. A control cycle has been developed to allow the engine installed in the test cell to simulate vehicle operation on the light-duty chassis dynamometer for two cycles—an initial preparation cycle to ensure that stable operating conditions can be achieved, and a second cycle to provide emission samples.

Optimization of the EGR system is one of the primary approaches to be used to reduce engine-out NO_x levels. A low-pressure EGR system is currently being installed on the engine and mapped over a range of engine conditions—a total of 300 individual points during which engine operating conditions and exhaust constituents are being measured. Several mode identification strategies were tested in June to measure engine-out mass emissions of NO_x and PM. Initial tests indicate that an optimized EGR strategy in conjunction with intake throttling will reduce engine-out NO_x from 60 to 70 percent.

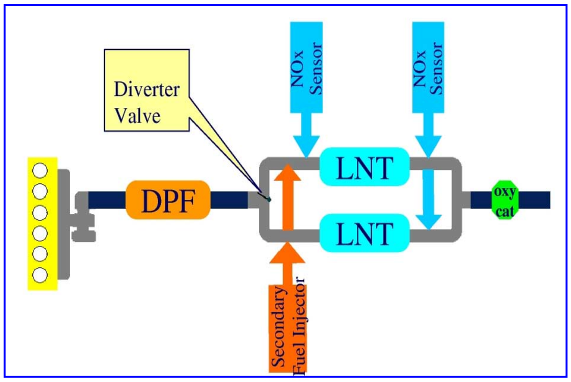


This schematic (ECS-B) shows a dual leg emission control system configuration—one of the two proposed systems to be tested.

The laboratory has acquired the hardware for building and installing the engine in the test cell. The second test vehicle and the first set of ECS devices have been received. The NO_x adsorber catalysts were delivered in June and the diesel oxidation catalysts (DOC) were received in July. Thermal management and exhaust heat generation strategies are being tested with a focus on intake throttling, post injection, and the diesel burner injection controls.

During July, the exhaust systems in the test cell were modified to accommodate the diesel fuel burner. Cold start testing and thermal analysis of the burner are also being conducted. SwRI has all the necessary after-treatment components to perform the work required during this phase. Work during the summer will include recalibrating the engine to minimize the engine-out NO_x concentrations and to optimize the ECS. The baseline engine-out testing with the fuels (8- and 15-ppm S and the BP15 refinery fuel) began in August and is expected to be completed in October.

- **Ricardo, Inc., Burr Ridge, IL, test bed: a heavy-duty engine** (15L Cummins ISX, DOHC engine). This project is currently developing a rich operating strategy by refining the in-cylinder, post-injection capability, EGR/variable nozzle turbine (VNT) management, in-pipe injection, and throttling. The purpose is to optimize the injection calibrations with the goal of lowering the engine-out emissions of NO_x from 2.5g/bhp-hr to 1.8-2.0g/bhp-hr—perhaps at the expense of PM increase.



In this schematic, System B has a dual NOx adsorber system for a heavy-duty engine installed in a test cell at Ricardo, Inc.

Two after-treatment systems are to be tested: System A and System B. **System A** has a single NO_x adsorber catalyst and the engine will be required to cycle lean/rich to regenerate the NO_x adsorber catalyst, using a combination of increased EGR, in-cylinder and in-pipe post injection. **System B** (see schematic**)** will have a dual NO_x adsorber catalyst system, so the engine will not be required to cycle lean/rich to regenerate the catalyst. In System B, rich conditions will be achieved by injecting fuel upstream of the bypassed catalyst.

The catalyst systems are being modeled to simulate exhaust temperatures that may exist throughout the after-treatment system, adsorber and DPF loading under transient and steady-state conditions, and sulfur effects. The catalyst systems will also examine tradeoffs of sizing, activity, configuration, and positioning in the exhaust on NO_x reduction efficiency and fuel consumption, as well as for NO_x adsorber regeneration under rich conditions/desulfurization under hot and rich conditions and DPF regeneration. Both catalyst systems A and B will be tested initially up to 300 hours of aging on 8-and 15-ppm S fuel. Either System A or B will then be selected for an additional 1,200 hour aging test (1,500 hours total).

The DPF and DOC technologies for System A, which allow for the validation of rich regeneration, have been received. The components for System B are expected in late August. The lab has received the 0.6-ppm S fuel, the 8- and 15-ppm S fuels, and the BP15 fuel. Baseline tests will be conducted in September.

Lubricants – Automotive Testing Laboratory (ATL), East Liberty, OH, test bed:

Navistar T444E, 7.3L V8 engine, with retrofits installed. The objective of this project is to determine which, if any, lubricant-derived components in emissions are detrimental to the performance or durability of emission control systems. Phase I analyzed a matrix of additives in combination with four basestock oils and concentrated on acquiring and analyzing emissions data to determine how lubricants-derived components affect engine-out emissions, and which have the potential to affect the performance and durability of vehicle ECS systems.

Lubricants. Testing of lubricant formulations is being conducted in a heavy-duty engine test cell. The test engine is installed on a dynamometer combining a double-ended GE DC-electric brake (200hp) with a Go-Power DT-2000 water brake (800hp), which provides precise control and high torque/power absorption capability on a single in-line assembly.

Thirteen additives in combinations with four basestocks were tested for PM (with detailed breakdown analysis), HC, CO, NO_x, and SO_2. Each oil (with additives) was tested during repeated four mode steady-state tests. Analyses of oil/additive combinations were performed at the beginning and end of Phase I tests. On May 30, a Phase I data review and Phase II planning meeting were held at ATL.

ATL is now working on Phase II, which will concentrate on developing a rapid aging protocol to test lubricant effects on catalysts. Approaches include fuel/oil blending, oil injection into the exhaust, ring pack modifications, and various combinations of these approaches.