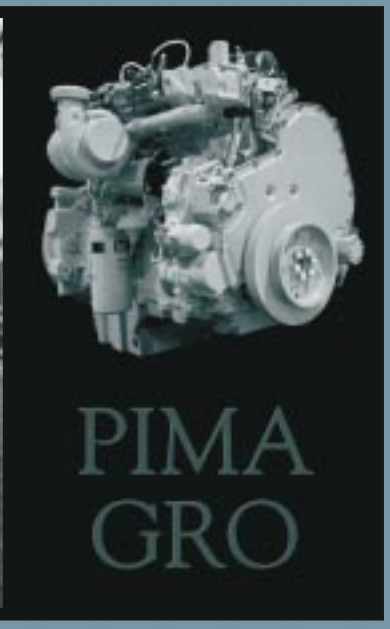
Dual-Fuel Truck Fleet

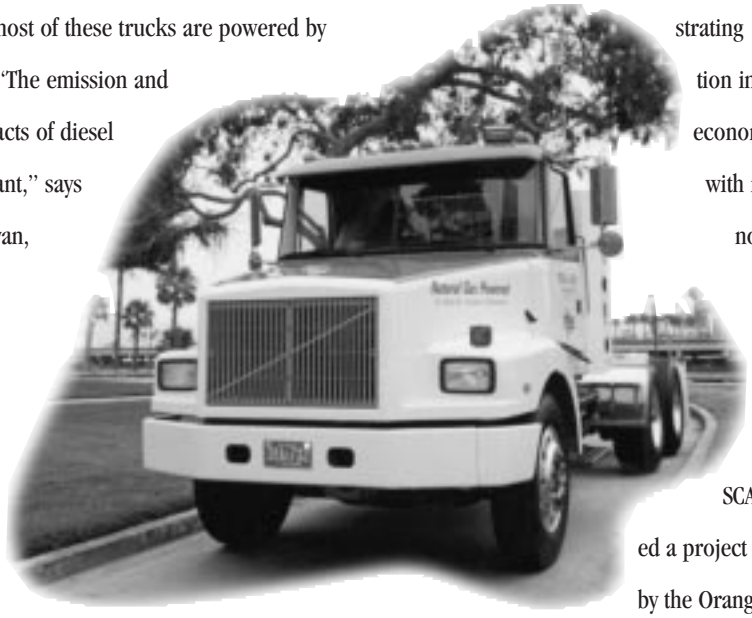
Start-Up Experience



Alternative Fuel Truck Evaluation Project

California's South Coast Air Quality Management District (SCAQMD) serves as the air pollution control agency for a four-county region that includes Los Angeles and Orange counties and parts of Riverside and San Bernardino counties—a 12,000-square-mile area with a population of more than 14 million people. Although not directly responsible for controlling pollution from motor vehicles, SCAQMD conducts transportation-related programs to reduce the mobile sources that account for most pollutants that form ozone and particulates. One of SCAQMD's current programs is a demonstration of dual-fuel engine technology in heavy-duty trucks. These trucks are being studied as part of the National Renewable Energy Laboratory's (NREL's) Alternative Fuel Truck Program. This report describes the start-up experience from the program. A detailed report on the performance of the trucks will be published after the trucks' first year of service.

According to the California Air Resources Board (CARB), heavy-duty trucks account for 2 percent of the vehicles in California, but contribute nearly 30 percent of oxides of nitrogen (NO_X) and more than 65 percent of particulate matter. And, as CARB indicates, most of these trucks are powered by diesel fuel. "The emission and health impacts of diesel are important," says Cindy Sullivan, SCAQMD program supervisor. "We need to reduce diesel emissions not only to clean the air, but also to lessen the health impacts to our citizens."



To further the goal of reducing diesel emissions, SCAQMD solicited proposals in 1996 to develop and demonstrate the use of alternative fuel engines with NO_X emissions of 2.5 g/bhp-hr in fleet vehicles. "We wanted to get past the prototype stage and get some operations information," Sullivan says. "With this project, we wanted to reduce emissions of NO_X and other regulated pollutants. We also hoped to encourage commercial fleets to use alternatives to diesel engines in heavy-duty trucks by demonstrating the reduction in emissions economically with new technologies." Through a formal request for proposals, SCAQMD selected a project proposed by the Orange County Sanitation District (OCSD). OCSD is a public agency responsible for collecting, treating, and safely disposing of wastewater for 2.2 million residents and businesses in metropolitan Orange County, California. OCSD treats about 250 million gallons of wastewater each day with facilities that include 26 pumping stations, 650 miles of sewer pipelines, and two modern treatment plants located in Fountain Valley (Reclamation Plant No. 1) and Huntington Beach (Treatment Plant No. 2).

OCSD's operation includes the transportation of approximately 3,800 tons a week of biosolids from the treatment plants. (Biosolids are the organic materials derived from the wastewater treatment process.) OCSD contracts with commercial haulers to transport the biosolids.

OCSD proposed to work with a commercial operator to demonstrate the Caterpillar 3176B fitted with electronically controlled dual-fuel engine technology in trucks hauling biosolids from the OCSD facilities in Fountain Valley to Kern County. As part of the project, OCSD also proposed to install a compressed natural gas (CNG) fueling facility at its Fountain Valley site. OCSD planned to provide the fuel to the contracted biosolids haulers and to allow public access to the facility. OCSD's mission, according to Ed Hodges, director of the General Services Administration, is to protect the environment through excellence in wastewater treatment. "Our goal for this project," said Hodges, "was to clean up the air."

The trucks to be used in the project are operated by Pima Gro Systems, Inc., a commercial biosolids hauler under contract with OCSD. Pima Gro is an agricultural reuse company that specializes in recycling biosolids. Pima Gro loads biosolids at the OCSD facility and transports them to agricultural lands as organic fertilizer and soil amendment, which serves as an alternative to traditional chemical fertilizers.

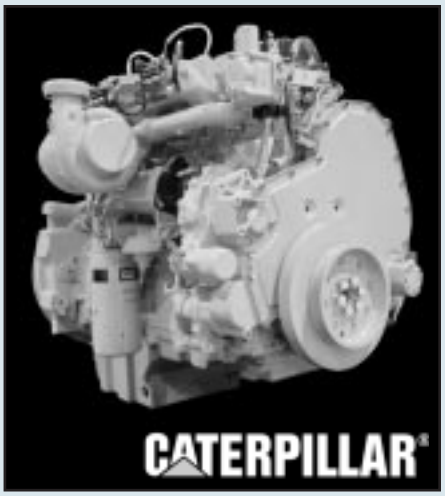
Gary Bruggeman, Pima Gro operations manager, emphasizes that the company's participation in the project is a perfect fit. "We are, for all intents and purposes, recyclers. We use all the recycled materials we can in order to preserve the environment. The CNG project with Orange County fits into our goals. We believe we need to do this to be good citizens."The waste-hauling operation uses a White/GMC Class 8 tractor, 3 Lincoln Composites CNG cylinders that provide total on-board capacity of 56 diesel equivalent gallons CNG and 105 gallons diesel, and the Caterpillar electronically controlled dual-fuel 3176B engine. Each truck makes a 350-mile round trip twice a day. The vehicles run four days each week, accumulating approximately 2,800 miles per truck weekly.

"A project like this one that moves beyond a prototype demonstration to an implemented operation has tremendous value," says Sullivan. "We need to establish emissions information about the engine, and we need to evaluate its durability. This particular program will provide the first data in the market about dual-fuel operations. To implement the technology commercially requires this kind of project."

The fleet demonstration and the resulting data from the evaluation provide some key benefits in the ongoing effort to implement alternative fuels in day-to-day trucking activities. The project will evaluate the merits of the technology and the costs of implementation, as well as helping to work through some of the bugs and roadblocks to make it easier for the next fleet.

To gather data about the performance of the engines and trucks and establish the reference for this technology, SCAQMD, OCSD, and Pima Gro are participating in NREL's Alternative Fuel Truck Evaluation Project. For the project, five trucks were repowered with the Caterpillar electronically controlled dual-fuel 3176B engine and three trucks were repowered with new 3176B engines that operate only on

Caterpillar 3176B Dual-Fuel CNG 10.3 L Engine



Performance Data

Operating range (rpm): 1200–2100
Maximum engine rpm: 2120
Maximum hp @ 2100 rpm: 350
Peak torque (lb-ft): 1050
Peak torque (rpm): 1200
Torque rise (%): 20
Altitude capability (ft): 7500

Certification Exhaust Emissions Standards (g/bhp-hr)

Non-methane hydrocarbons: 1.2
Carbon monoxide: 15.5
Oxides of nitrogen: 2.5
Particulates: 0.10

Note: The Caterpillar engine model in this size is now called C-10.

Source: Caterpillar, Inc.

Benefits of Electronically Controlled Dual-Fuel Engine Technology

- Offers similar power to diesel-powered engines
- Lower emissions than diesel equivalent
- Same heat rejection as diesel
- High gas substitution rate
- Attractive operating economics, depending on fleet location and mileage
- Compatible with compression brake installation
- Full use of standard diesel electronic diagnostic and fleet management tools
- Warranty administered through local Caterpillar dealer
- Resale value advantages (versus dedicated gas)
- Full diesel backup (80% power in California)

Source: Caterpillar Engine Division

diesel fuel. Battelle, NREL's technical project manager, will collect data to compare operations, emissions, and cost data between dual-fuel CNG trucks and the baseline diesel trucks.

How Does a Dual-Fuel Engine Work?

Although dual-fuel engine technology has been in development and limited use for several years, it has only recently moved toward full-scale operational capability for heavy-duty truck applications. Unlike a bi-fuel engine, which has two separate fuel systems that are used one at a time, a dual-fuel engine uses two fuel systems simultaneously. Flexible-fuel engines, which allow a vehicle to operate on either fuel or a combination of the two, are not currently available for heavy-duty truck operations.

For example, a bi-fuel diesel/natural gas vehicle has two fuel systems that allow it to operate using either diesel or natural gas. A dual-fuel engine using diesel and natural gas uses the natural gas as its primary fuel source and a small amount of diesel fuel for a pilot charge to ignite the natural gas.

The multi-fuel capability of the dual-fuel engine allows a truck to operate in diesel-only mode in emergency situations. In this mode, the engine is restricted to 80 percent of its available power, but it does provide essential backup for an operator.

According to Power Systems Associates (PSA), the manufacturer and installer of the Caterpillar electronically controlled dual-fuel 3176B engines used in the project, combining diesel and natural gas allows the engine to retain the diesel compression ratio and fuel economy and to substitute diesel fuel with less expensive, cleaner burning natural gas. As PSA describes it, the engine uses multi-point, port-injected natural gas delivery valves and electronically controlled diesel injection to achieve nearly full diesel power and diesel-like efficiency with lower emissions.

The natural gas injector and sensors are mounted on the dual-fuel intake manifold.

Dual-fuel electronic control unit (ECU) controls air/fuel ratio, fuel quality and injection timing.

Development of the Caterpillar electronically controlled dual-fuel 3176B natural gas engine technology is a cooperative effort among Clean Air Partners, PSA, Caterpillar, Inc., Amoco, MVE, and the Gas Research Institute.

Converting Pima Gro's vehicles to dual fuel required a two-phase process. In the first phase,

PSA repowered the existing Caterpillar 3176 engines to Caterpillar dual-fuel 3176B engines. The installed dual-fuel engine started with a stock diesel engine. The stock Caterpillar air intake manifold is removed, and a preconfigured Caterpillar air intake is reinstalled, complete with natural gas injectors, porting tubes, sensors, and gas shut-off solenoid. The injectors are connected to the dual-fuel system's electronic control unit (ECU)—called the Eagle—with a special wiring harness, and the ECU is linked to the diesel engine's electronic control module (ECM). The second phase involves adding the new fuel system to the vehicles, which was installed on the Pima Gro trucks by the NGV Ecotrans Group of Los Angeles. Ecotrans added the new fuel tanks, mounting system, and fuel rail. The cost of the conversion, which was shared by SCAQMD and Pima Gro, is approximately $45,000 for each vehicle, including the new engine.

The Caterpillar dual-fuel engine's two fuel systems are controlled by the gas system ECU. As PSA describes the process, Servojet's Eagle ECU intercepts the Advanced Diesel Engine Management (ADEM) system's desired diesel fuel injection signal via the diesel engine ECM and returns a request for diesel injection of a specific quantity, at a specific time in the combustion stroke.

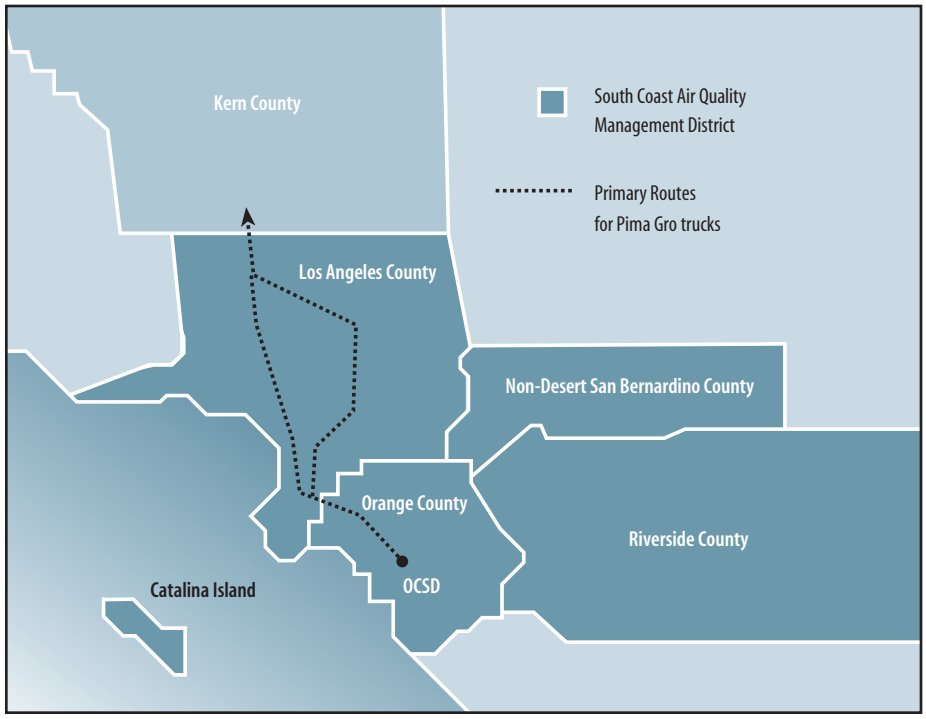
The Eagle simultaneously and sequentially sends a pulse-width-modulated signal to the six gas injectors located on the modified intake manifold, metering gas delivery quantities. The combined gas and diesel quantities make up the precise amount of fuel to provide the proper power response to throttle positions. The six gas injectors are supplied with natural gas at a rail pressure of 125 psi. The pulse width signal is adjusted with respect to manifold pressure, charge air temperature, gas temperature, and fuel mapping designed to duplicate base diesel performance.

The engine uses a skip-firing technique to improve gas substitution and emissions at low rpm (e.g., idle, heavy traffic, and light loads). Skip firing, which starts gas/diesel combustion in a minimum of three cylinders upon throttle demand, continues to add cylinders one at a time until full power is reached on six cylinders. This technique enables optimum air to fuel ratios to allow for complete combustion in transition between full diesel at idle to full power on the combined fuels. The dynamic result of this technique can give the driver a sense of "engine miss." This sensation, however, is normal.

The skip-fire routine in transition at idle on diesel to full power on combined fuels is taken into account when certifying the engine in accordance with the emissions testing procedures to which this 2.5g/bhp-hr engine was certified.

What Has Made the Project Successful?

Pima Gro began operating the first dual-fuel truck in February 1997. The truck has been used heavily, averaging 8,000 miles per month. At this point in the project, five dual-fuel trucks have been repowered with new engines and are in service. The trucks' severe duty cycle (they travel off-road to deliver the biosolids) initially caused problems with fuel leakage, but the problem was resolved by redesigning the fuel cylinder mounting, which had been loosened by vibration. Battelle is currently collecting data on operations, maintenance, duty cycle, safety incidents, capital costs, and operating costs, and



West Virginia University used its transportable chassis dynamometer to test emissions in July 1998.

The most significant setback for the project has been the time and difficulty involved in procuring a compressor for the fueling station that OCSD is building at its facility. Fuel for the fleet is currently provided by a Southern California (SoCal) Gas Company CNG station in Glendale. The permanent station—a $1.4-million, 1,200-scfm unit—should be installed and operating by fall of 1998.

Although there have been a few equipment and administrative issues to resolve, Ed Hodges believes that the success of the project rests in the strength of the partnership that has developed among the participants, and Cindy Sullivan agrees. "We need to address heavy-duty truck emissions, and we need to do it now," Sullivan says. "And partnerships like this one will make it work."

The partnership that Sullivan and Hodges describe includes seven key participants who each played a key role in the start-up and ongoing operation of the project:

- **SCAQMD,** primary funding organization and project manager
- **OCSD,** prime contractor, facilitator, and fuel station operator
- **SoCal Gas Company,** contributor of in-kind technical support for the fueling site
- **Pima Gro Systems, Inc.,** demonstration fleet operator
- **Power Systems Associates,** manufacturer/installer of the Caterpillar dual-fuel 3176B engines and distributor of stock Caterpillar diesel engines
- **NREL,** funding agency for data collection, evaluation, and emissions testing
- **Battelle,** support contractor for data collection and evaluation, troubleshooting, and technical coordination of the team.

Hodges praises the benefits of public-private partnerships. "Bringing these players together and establishing the partnership of public agencies, such as the SCAQMD and OCSD, with commercial fleet operators, such as Pima Gro, enables everyone to meet individual goals and share in meeting the ultimate goal of cleaner air in Southern California," he says.

Hodges sees even more potential for the arrangements to change the way public agencies do business. "When you look at the future of our industry, you are going to see more of these partnerships. It is great to imagine a public agency running like a business. I believe that public agencies have a duty to their shareholders, and in my case, it's the 2.2 million people of Orange County. I owe them to operate this facility as efficiently as possible." Hodges believes that incorporating alternative fuels into OCSD's operations

To Learn More About Dual-Fuel Engine Technology

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U.S. Department of Energy, *Heavy-Duty Vehicle and Engine Resource Guide,* National Alternative Fuels Hotline, 1-800-423-1DOE.

allows the agency not only to uphold its environmental mission but to explore opportunities—such as public use of the fueling facility—to generate income for the sanitation districts. The income can then be used to offset user fees for the 2.2 million "shareholders" that OCSD serves.

In addition to recognizing the significance of the public-private dimension of the project, the team identified a few key factors that can contribute to the success of future projects:

Find a champion. Sullivan emphatically stresses this point: "Look at any of the alternative fuel projects, whether it's trucks or buses. If an organization wants it to work, it will work. You can make it work. But you must have a champion. Nothing in this project would have happened without Ed Hodges—he had the vision and he saw the big picture."

Emphasize communication among team members. OCSD has been the hub of contractual relationships of the partners, and Hodges has been the project's key facilitator. He emphasizes the need to stay close to the project during all phases of its development, keeping in touch with everyone from legal advisors to engineers. Communication is critical in a partnership that brings together public agencies and private enterprise. What may seem to be a concern only for mechanics can become a concern for everyone if a truck becomes inoperable. "Everyone needs to be on the same page," Hodges stresses, "or you can lose lots of valuable time."

Learn about the technology, and anticipate that you will have problems. Bob Shepherd, PSA's Dual-Fuel Program manager, stresses that anyone considering the use of new technologies needs to anticipate problems. "In the infancy of any technology, there will be a learning curve in understanding how the system works and how it may be different from the customary applications," Shepherd points out. "However, as long as you keep the goal in sight, you can be successful. Our goal—reduced emissions from the heavy-duty vehicle sector—keeps us moving forward on developing this technology." Sullivan also emphasizes this point: "Fleets often expect that this won't be different. It will be different. It will be a challenge."

Bruggeman advises commercial operators who are planning to implement alternative fuels to dig deeply for information and find out what is needed. "You need to understand the technology and its implications," Bruggeman stressed. "Find reliable sources of information—don't rely on assumptions." Bruggeman also emphasized the importance of working with partners who understand commercial operations. "Make sure they understand the impact if a fleet vehicle is out of service for even one day. In this project, EcoTrans and SoCal Gas provided invaluable support to us."

Train vehicle operators. There is a learning curve for drivers who will operate electronically controlled dual-fuel engines. In addition to learning safety procedures for CNG, drivers need to learn the feel of the engine and to get used to it. Without proper information, drivers may assume that the skip-firing they may be feeling is a problem with an engine rather than its normal operation.

Drivers need to have confidence to operate the engines—the diesel backup is intended for use only to provide safe vehicle operation ("limp home") when the dual-fuel mode fails or when there is insufficient CNG on board for dual-fuel operation. Drivers need to understand that the diesel-only mode will give them only 80 percent power: they need to learn to operate the trucks using natural gas. As Bruggeman clearly states, "I really believe that natural gas is the fuel of the future. If you are going to be in the trucking business, you might as well get used to it."

The Alternative Fuel Truck Evaluation Project

The Alternative Motor Fuel Act of 1988 requires the Department of Energy (DOE) to demonstrate and evaluate alternative fuels usage in the United States. DOE's National Renewable Energy Laboratory (NREL) is conducting the Alternative Fuel Truck Evaluation Project to compare alternative fuel and diesel fuel trucks. Information for the comparison comes from data collected on the operational, maintenance, performance, and emissions characteristics of alternative fuel trucks currently being used in vehicle fleets and comparable diesel fuel trucks serving as controls within the same fleet. In 1993, NREL began a similar program to evaluate transit bus use. The defined and proven data collection and analysis system from the bus study has been adapted for the heavy-duty truck project. The sites in the program are selected according to the type of trucks and engines used, the availability of control vehicles, and interest in participating. Specific criteria must be met, and the fleet must include at least five alternative fuel trucks.

This report highlights the start-up experience of a partnership project being conducted in Orange County, California. After collecting 12 months of data from the site, NREL and Battelle, NREL's support contractor for the project, will prepare a formal report and analysis.

If you want to know more about this dual-fuel truck program, its components, alternative fuel vehicles, or incentive programs, contact any of the following:

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For more information and for copies of program reports, visit the Alternative Fuels Data Center on the World Wide Web at ***http://www.afdc.doe.gov****, or call the National Alternative Fuels Hotline at* ***1-800-423-1DOE.***

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