ARGONNE NATIONAL LABORATORY

Engine and Vehicle Systems Research

Winter 1999

OVERVIEW

The measure of any government research facility should be taken not only in its equipment and machinery but also in the success of its people who use that equipment to create new ideas and technologies on behalf of the American economy.

Argonne's skilled staff brings extensive engine manufacturing experience and associated engine/vehicle modeling capabilities to the development of advanced technologies that improve engine performance, increase fuel economy, and reduce emissions.

Argonne's researchers invent solutions to problems that face the engine manufacturing industry.

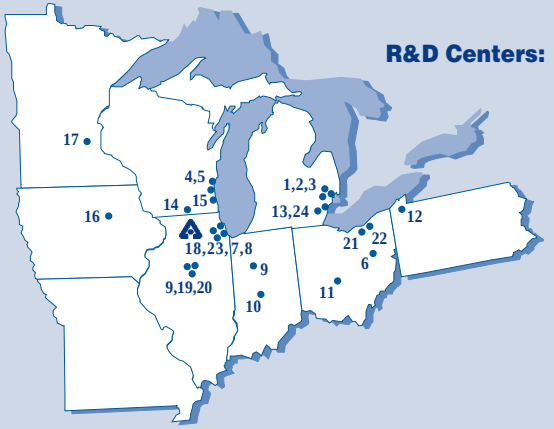
Argonne-developed technologies include novel approaches to

- Improving fuel economy and power density
- Reducing exhaust emissions
  - particulates and smoke in diesel engines
  - carbon monoxide, hydrocarbons, air toxics, and aldehydes in gasoline engines
  - nitrogen oxides (new patents for in-cylinder and aftertreatment control)
- Using low-grade and non-petroleum fuels

Argonne recently launched a unique facility for evaluating the efficiency and effectiveness of hybrid electric vehicle (HEV) technology. The Advanced Powertrain Test Facility will "map" the performance of typical component designs and systems and provide valuable baseline data about HEVs to support modeling work done for the U.S. Department of Energy's (DOE's) HEV programs. The flexible facility can also be used to test and develop direct-drive, or stand-alone, engine technologies. Integrated exhaust emissions testing equipment allows testing of both spark-ignition (SI) and compression-ignition (CI) engines using both conventional and alternative fuels.

Industry's confidence in Argonne's staff and capabilities is demonstrated by a willingness to invest significant research dollars at Argonne.

General Motors' Electro-Motive Division (EMD) has invested $4 million (100% corporate funding) to establish a multiyear research program and a single-cylinder locomotive test facility at Argonne. EMD is supporting research to enhance techniques that will reduce diesel engine emissions – techniques that Argonne developed that are also applicable to heavy-duty truck and light-duty diesel engines. Innovations by Argonne staff in diesel emission control technologies have attracted additional interest from other engine manufacturers and suppliers.



R&D Centers:

Light-Duty Vehicles
1. GM
2. Ford
3. Chrysler
4. Outboard Marine
5. Harley-Davidson
6. Hercules

Heavy-Duty Engines
7. Navistar
8. EMD
9. Caterpillar
10. Cummins
11. Cooper
12. General Electric
13. DDC
14. Fairbanks-Morse
15. Waukesha
16. John Deere
17. ONAN

Fuel
18. Amoco
19. ADM
20. Pekin Energy Systems
21. Lubrizol
22. B-P Oil Co.

Associations
23. EMA
24. USCAR

Argonne's location, in the heart of the nation's automotive, truck, and engine (gasoline and diesel) manufacturing industry, facilitates frequent, personal, and cost-effective interaction between Argonne researchers and industry representatives. Argonne is easily reached from Chicago's two major airports, O'Hare and Midway.

ARGONNE'S ENGINE AND VEHICLE SYSTEMS RESEARCH STAFF

Engine and Emissions Research

Raj Sekar, Section Leader
- MS, Mechanical Engineering, University of Wisconsin
- MBA, Indiana University (R&D Management)
- Over 30 years of engine research experience (15 years at Cummins Engine Co.)
- 5 patents and over 35 reviewed publications in engine-related technologies

Roger Cole, Technical Staff, Mechanical Engineer
- PhD Mechanical Engineering, Northwestern University
- 26 years of energy R&D experience at Argonne (10 years in diesel cogeneration systems)
- 2 patents and over 30 publications related to power systems
- Conducted research on vehicle emissions, turbines, and transmissions at Ford Motor Co.

Greg Krumdick, Technical Staff, Electrical Engineer
- MS, Electrical Engineering, University of Illinois at Chicago
- 8 years of experience in instrumentation, controls, and computer applications

Doug Longman, Technical Staff, Mechanical Engineer
- BS, Engineering, University of Illinois
- 15 years of engine and fuel systems testing experience (9 years at Caterpillar, Inc.)
- 2 patents
- Conducts experiments on engine performance and emissions

Ramesh Poola, Technical Staff, Mechanical Engineer
- PhD, Mechanical Engineering, Indian Institute of Technology, Madras
- 8 years of experience in engine fuel economy and emissions research
- 2 patents and over 30 reviewed publications in engine and emissions technologies

Kevin Stork, Technical Staff, Chemical Engineer
- BS, Chemical Engineering, University of Virginia
- 3 years of experience in air separation membrane design for engine applications
- 5 years of experience in economic assessments for transportation systems

Sreenath Gupta, Post Doc
- PhD, Mechanical Engineering, Penn State University
- Specializes in combustion and emissions
- Develops laser-based particulate measurement systems

Dennis Assanis, Special Term Appointment, since 1989
- Professor, Mechanical Engineering, University of Michigan
- At Argonne, conducts computer simulation for engine-cycle analysis

Matt Lagessie, Senior Electro-Mechanical Technician
- 15 years of internal combustion engine experience

Sherman Smith, Senior Electro-Mechanical Technician
- 35 years of laboratory experience

Fuels and Vehicle Systems Research

Robert Larsen, Section Leader
- MS, Program Management, University of Wisconsin-Madison
- 13 years of alternative fuels and vehicle systems experience at Argonne
- Developed hybrid vehicle testing and instrumentation procedures
- Member, Board of Directors, Society of Automotive Engineers (SAE) International

U.S. Department of Energy Secretary Bill Richardson dedicated Argonne's Transportation Technology R&D Center in September 1998.

Carlos Buitrago, Technical Staff, Mechanical Engineer
- MS, Mechanical Engineering, Old Dominion University
- 4 years of experience in engine testing and data acquisition/analysis
- Designed gaseous fuel injector now produced by Siemens

Roy Cuenca, Technical Staff, Mechanical Engineer
- MS, Mechanical Engineering, Northwestern University
- 40 years of experience in engine and component design, testing, and evaluation
- 14 years with Cummins Engine Co., member of design team for K-6 engine
- Experienced in engine/component cost analysis and strategic planning (SRI International)

Michael Duoba, Technical Staff, Mechanical Engineer
- MS, Mechanical Engineering, University of Wisconsin-Madison
- 7 years of engine, battery, and hybrid vehicle research (extensive chassis dyno expertise)
- Consultant to SAE J1711 standard development committee for HEV test procedures
- Consultant to the California Air Resources Board (CARB) and U.S. Environmental Protection Agency (EPA) on HEV test procedures

Donald Gray, Faculty Research Participant
- PhD, Electrical Engineering, Purdue University
- Professor, Electrical Engineering, Purdue University
- Expert in neural net control systems
- At Argonne, developing engine and hybrid control systems and instrument and data acquisition systems for powertrains

Argonne's Advanced Powertrain Test Facility

Cynthia A. McFadden, Technical Staff, Mechanical Engineer
- BS, Mechanical Engineering, Utah State University
- Advanced Vehicle Technology Competition program manager
- Former team leader, Propane Vehicle Challenge

Henry Ng, Technical Staff, Mechanical Engineer
- PhD, Mechanical Engineering, University of Wisconsin-Madison
- 13 years of experience in engine research and emissions control
- Set up test cell for optical engine diagnostics at Sandia, while at Cummins Engine Co.

Richard Gonzales, Special Term Appointment, since 1995
- PhD, Electrical Engineering, University of Illinois, Urbana
- Professor, Electrical Engineering, Purdue University
- At Argonne, develops experimental control systems, instrumentation, and testing protocols

RECENT ARGONNE PATENTS ON ENGINE TECHNOLOGIES

1998 Method and Apparatus for Reducing Diesel Engine Exhaust Emissions (Patent Filed)

This invention relates a method and apparatus for reducing undesirable emissions in the exhaust of a diesel engine by injecting controlled quantities of supplemental air (that may include oxygen-enriched air) directly into the combustion chambers of the engine during the portion of the combustion cycle when the piston in each combustion chamber is in its expansion and/or exhaust stroke.

1998 Method and Apparatus for Reducing Particulates and NO_x Emissions from Diesel Engines Utilizing Oxygen-Enriched Combustion Air (Patent Filed)

This invention relates a method and apparatus for decreasing both particulates and oxides of nitrogen simultaneously from the diesel engine exhaust by introducing oxygen-enriched air and an increased quantity of fuel by retarding the fuel injection timing.

(continued on next page)

1997 Variable Oxygen/Nitrogen-Enriched Intake Air System for Internal Combustion Engine Applications (#5,649,517)

By changing the air composition (either oxygen-enriched or nitrogen-enriched air) based on engine demand with an onboard air separation membrane, many emissions-related problems in both CI and SI engines can be minimized. A practical method using a membrane to vary the oxygen-to-nitrogen ratio in the engine intake system and control system to supply air on demand was disclosed in this invention. Also, the application of nitrogen-enriched air from the membrane for an exhaust after-treatment device was included.

1997 DeNO$_x$ Device (#5,640,845)

This spark plug-like device produces monatomic nitrogen in the exhaust manifold. An onboard air-separation membrane supplies nitrogen-enriched air to this device to generate monatomic nitrogen with an arc between the electrodes. This process enables the nitrogen plasma aftertreatment to reduce NO_x.

1997 Method and Apparatus for Reducing Cold-Phase Emissions by Utilizing Oxygen-Enriched Intake Air (#5,636,619)

This invention discloses a method and apparatus for using oxygen-enriched combustion air supplied by an onboard air-separation membrane during the initial start-up and warm-up periods of light-duty vehicles to reduce NMHC/NMOG, CO, air toxics, and aldehydes (in alternative-fuel vehicles).

1996 NO_x Reduction Method (#5,526,641)

This invention discloses a method of reducing NO_x in the exhaust of an internal combustion engine. This concept uses nitrogen-enriched air from an air-separation membrane that is subjected to a corona or arc discharge to create a plasma and, as a result, monatomic nitrogen. The monatomic nitrogen is injected into the exhaust of the internal combustion engine, which reduces the NO_x in the exhaust into nitrogen and oxygen.

Ronald Matthews, Special Term Appointment, Mechanical Engineer

- PhD, Mechanical Engineering, University of California-Berkeley
- Professor, Mechanical Engineering, University of Texas at Austin
- 25 years of experience in engine R&D
- At Argonne, researching fuels and SIDI engine technology

ENGINE TEST FACILITIES AT ARGONNE

Major Facilities

Advanced Powertrain Test Facility (Building 371)

This unique facility was designed to test conventional and hybrid electric vehicles, drivetrains, and components. The powertrain dynamometer can be used to perform component characterizations and test entire drivetrains by simulating any vehicle driving load.

- 190-hp motoring DC dynamometer
- Dynamometer control system
- 40-kW, permanent magnet DC electric motor
- 1.0-L, 55-hp, spark-ignition engine
- 180-V, 4-kW/h lead acid battery pack
- Data acquisition system
- Fuel scale
- Horiba Emissions Analyzer Bench (NMHC, THC, CO, NO_x)
- Horiba Constant Volume Sampler
- Pierburg AMA 2000 Exhaust Gas Measurement System
- Sierra BG-1 Micro-Dilution Test Stand
- Cambustions Real-Time, 2-Channel NO_x and HC Analyzer
- Laser Nephelometer Real-Time Particulate Size and Composition Measurement System
- Varian 3400 Gas Chromatograph (for gasoline vehicles)
- Varian 3700 Gas Chromatograph (for alternative fuel vehicles)

- Clayton Twin Roll Electric Dynamometer (weight selection up to 9,125 lb)

Locomotive Engine Test Facility (Building 376)

This unique world-class test facility enables researchers to study high-pressure fuel injection systems, in-cylinder and aftertreatment of exhaust emissions, and methods to improve power and fuel economy.

- 400-hp, single-cylinder locomotive diesel engine
- 700-hp eddy current dynamometer
- 200-hp air compressor
- Diesel fuel system (fuel scale, 200-gal indoor tank, 1,000-gal outdoor tank, pumps)
- Electric heaters and heat exchangers (for heating and cooling engine air, lubrication oil, jacket water, and fuel)
- Engine control and performance data acquisition system
- Engine combustion analysis system: AVL-Indiskop (engine in-cylinder pressure, crank angle, and peak cylinder pressure)
- Smoke opacity meter (AVL)

Argonne-Owned Experimental Equipment at AutoResearch Laboratories Inc. (ALI)

The following special equipment was designed, fabricated, and procured by Argonne for experiments relating to variable air composition in light-duty, heavy-duty, and locomotive diesel engines. Argonne also developed test procedures and data reduction programs for this research.

- 1.9-L, four-stroke, turbocharged, compression-ignition, direct-injected Volkswagon diesel engine
- Enhanced air handler unit to supply oxygen-enriched intake air (up to 35% pure oxygen) from bottled gases (for vehicle Federal Test Procedure [FTP] tests)
- Control systems to supply and mix pure oxygen or nitrogen with intake air for IC engines
- High-speed data acquisition system to record combustion parameters (cylinder pressure, crank angle, injection timing, needle lift, rocker-arm strain, and spark timing)
- Cylinder pressure transducers, optical encoders, instrumented spark-plug to measure cylinder pressure
- Instrumented rocker-arm to measure strain (fuel injection timing) and bridge amplifier
- High-precision temperature sensors for cooling load measurement
- Electrical aerosol analyzer and condensation particle counter for particulate size and number density measurements
- Mini-dilution tunnel and particulate filter assembly for total particulate mass measurement using gravimetry technique

Bench-Scale Facilities

Fuel Spray Characteristics Test Facility (Building 315)

This facility enables evaluation of fuel injection design parameters by measuring fuel spray characteristics, including spray penetration, spray angle, drop size distributions, velocity fields, and fuel-air mixing patterns.

- Pressure vessel (1,000 psi)
- 1-dimensional Phase Doppler Particle Analyzer
- High-speed camera
- Charge-coupled device imaging system
- Lighting system for imaging
- Pressure measurement system (transducer, charge amplifier)
- Data control and image/data acquisition system

Test Rig: Non-Thermal Plasma for NO_x Control (Building 315)

This facility has a reaction chamber to analyze the effectiveness of monatomic nitrogen induced by pulsed plasma in reducing NO_x emissions. Design parameters, such as exhaust constituents, oxygen levels, plasma frequency and power, and purity of nitrogen, can be varied independently in optimization studies for exhaust gases from both gasoline and diesel engines.

Air Separation Membrane Bench Test Facility

- Nitrogen plasma device
- High-voltage pulser (generates monatomic nitrogen)
- Data acquisition system
- Nitrogen oxides analyzer (NO and NO_x)
- Oxygen analyzer

Air Separation Membrane Bench Test Facility (Building 315)

Membrane units with flows up to 200 cfm can be tested under vacuum to evaluate membrane performance (selectivity, stage cut, purity of oxygen or nitrogen, pressure ratios) and power requirements for engine applications.

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- 10-hp vacuum pump
- 14-hp roots blower
- Air separation modules
  - A/G Technology: 7 cartridges, each about 3 in. in diameter and 48 in. long
  - Compact Membrane Systems, Inc.: 5 cartridges with different sizes
- Airflow elements
- Mass airflow computer
- Duct air heater
- Oxygen analyzer

Two-Stroke Engine Test Rig (Building 376)

Engine tests with instrumented piston for measuring instantaneous piston temperature data under engine load conditions are being conducted with either carbureted or direct-injected gasoline engine.

- 25-hp, single-cylinder, two-stroke, spark-ignition engine
- 30-hp eddy current dynamometer
- Engine test stand
- Fuel scale
- Engine data acquisition system (for high-speed, in-cylinder pressure and temperature data)
- Infrared telemetry system (measures piston temperatures)

AUTOMOTIVE ENGINE AND EMISSIONS RESEARCH EXPERIENCE

Evaluation of Spark-Ignited, Direct-Injection Engine in Light-Duty Vehicles

1998 - Current **DOE** *(Sponsor)*

Tests on a Mitsubishi vehicle with an SIDI, gasoline-fueled engine have been completed. Comprehensive tests on SIDI completed, including effects of fuel composition and volatility on emissions and fuel economy.

Advanced Emissions Control Research on Heavy-Duty Diesel Engines

1998 - Current **Argonne/LDRD** *(Sponsor)*

In-cylinder injection of oxygen-enriched air during the later part of the diesel combustion cycle to reduce smoke and particulates, an invention disclosed by Argonne, is being investigated with multidimensional engine modeling and single-cylinder experiments on a truck diesel engine.

Nitrogen-Enriched Intake Air to Reduce NO_x from Passenger Car Diesel

1997 - Current **CMS, Inc.** *(Sponsor)*

Engine-dynamometer tests are being conducted to examine the effectiveness of nitrogen-enriched intake air supplied by an air separation membrane to reduce NO_x emissions from a 1.9-L, four-stroke, turbo-charged, Volkswagen diesel engine.

Direct-Injection of Fuels in Reciprocating Engines

1997 - Current **Argonne/LDRD** *(Sponsor)*

Fuel spray characteristics are being evaluated in a bench-scale facility with a high-speed imaging system and Phase Doppler Particle Analyzer. Injection systems to be tested include conventional diesel injection, high-pressure common rail injection, and natural gas injection.

Advanced Powertrain Testing

1997 - Current **DOE** *(Sponsor)*

Argonne staff designed, constructed, and began operating the Advanced Powertrain Test Facility to measure efficiency of and emissions from HEV components and systems, including SI and CI engines. Staff also acquired emissions testing facilities and a chassis dynamometer; installation is to be completed in FY98.

EV/HEV Efficiency and Range Testing

1997 **DOE** *(Sponsor)*

Argonne staff measured EV and HEV on-road energy (watts/mile, state of charge [SOC]-corrected for HEVs) and charging efficiency for over 50 vehicles during the 1997 American Tour de Sol, a 300-plus mile, four-day event. Data were published in several journals.

Dedicated LPG Vehicle Emissions and Efficiency Testing

1997 **DOE and Texas** *(Sponsors)*

Argonne staff performed engine emissions (criteria pollutants, including HC speciation, modal emissions, and catalyst efficiency measurements) and fuel efficiency measurements for over 20 dedicated LPG-powered vehicles in the second Propane Vehicle Challenge at the Southwest Research Institute test facilities. Argonne established vehicle specifications and testing requirements, analyzed the results, and published a technical paper.

HEV Emissions and Efficiency Testing

1997 **DOE and U.S. Council for Automotive Research** *(Sponsors)*

Using advanced HEV testing protocols developed by Argonne, staff tested engines for emissions (criteria pollutants, CO_2, and aldehydes, when appropriate) and HEV drivetrains for energy efficiency (watts/mile) during the second FutureCar Challenge, using custom data acquisition systems developed by Argonne for SOC corrections at the U.S. Environmental Protection Agency's (EPA's) Ann Arbor, Michigan, facilities. Five different fuels plus electricity were tested.

EV and HEV Efficiency and Emissions Testing

1996 **DOE** *(Sponsor)*

Argonne staff tested HEV engine emissions (criteria pollutants) and efficiency (SOC-corrected) over FTP and New York City cycles using Argonne-developed HEV test procedures and instrumentation at the New York City Department of Environmental Protection's facilities. Argonne also dynamometer tested selected EVs for efficiency, and measured EV and HEV on-road (watts/mile) and charging efficiency for over 50 vehicles during the five days of the 1996 American Tour de Sol road rally.

Monatomic Nitrogen Aftertreatment

1996 - Current **Caterpillar** *(Sponsor)*

Laboratory experiments using simulated diesel engine exhaust gas were conducted with monatomic nitrogen, and NO_x reductions of up to 25% were observed in an unoptimized reaction chamber. Engine tests are planned.

Dedicated LPG Vehicle Emissions and Efficiency Testing

1996 **DOE and Chrysler** *(Sponsors)*

Using Chrysler testing facilities, Argonne staff directed engine emissions and efficiency measurements (including criteria pollutants, CO_2, speciated hydrocarbons [HCs], modal emissions, and catalyst efficiency measurements) for 12 dedicated propane-powered vehicles during the first Propane Vehicle Challenge. Argonne staff collected and analyzed data and published results in an SAE paper.

HEV Emissions and Efficiency Testing

1996 **DOE and U.S. Council for Automotive Research** *(Sponsors)*

Argonne tested 8 HEVs during the first FutureCar Challenge for engine emissions (criteria pollutants, CO_2, and aldehydes, where appropriate) and fuel efficiency (watts/mile, SOC-corrected) at EPA's Ann Arbor facilities using Argonne-developed energy measurement instrumentation and advanced HEV testing protocols. Four different fuels plus electricity were tested.

Locomotive Diesel (4SDI) Research

1996 - Current **General Motors Electro-Motive Division (EMD)** *(Sponsor)*

A new $4 million, single-cylinder diesel engine facility was built at Argonne to conduct research on advanced fuel systems, alternative fuels, and exhaust emissions. The data from this facility will be used to finalize the design of the multicylinder production engines at EMD. Some design improvements have already been identified for the power assembly and incorporated into the production design. All the emissions control research for EMD will be done in this facility.

EV and HEV Efficiency and Range Testing

1995 **DOE** *(Sponsor)*

Argonne provided instrumentation and collected data from EV and HEV competitions in Arizona, Virginia, Pennsylvania, and Indiana (over 50 vehicles in all), which allowed energy efficiency (watts/mile, SOC-corrected for HEVs) to be measured accurately.

EV and HEV Efficiency and Range Testing

1995 **DOE** *(Sponsor)*

Argonne staff conducted EV and HEV testing for efficiency (watts/mile, SOC-corrected for HEVs), performance, charging efficiency, and range by using Argonne-developed instrumentation on more than 40 vehicles during a five-day over-the-road competition during the 1995 American Tour de Sol.

CRADA with Mercury Marine

1995 - Current **DOE, Office of Heavy Vehicle Technologies** *(Sponsor)*

Mercury Marine, Argonne's partner, is switching to direct fuel injection (DFI) in its gasoline engines, which increases the piston's thermal loading. Argonne has developed an advanced piston instrumentation technique to investigate the use of thermal barrier coatings on the piston crown to eliminate thermal cracking problems. Experiments are conducted in Argonne's Engine Research Facility.

Argonne's partnership with EMD, one of the world's leading manufacturers of heavy-duty diesel engines for passenger and freight locomotives, aims to improve fuel efficiency, reduce emissions, and cut costs of diesel engines.

HEV Emissions and Efficiency Testing

1995 **DOE and California Air Resources Board** *(Sponsors)*

Argonne staff directed engine emissions (criteria pollutants, CO_2, and aldehydes when appropriate) and efficiency testing (SOC-corrected) for HEVs by using Argonne-developed protocols and instrumentation at the CARB's El Monte facilities. Staff also measured on-road efficiency (watts/mile, SOC-corrected for HEVs) for 35 HEVs and EVs over a three-day DOE-sponsored Clean Air Road Rally. Three fuels plus electricity were tested.

HEV Emissions and Efficiency Testing

1995 **DOE and Chrysler** *(Sponsors)*

Argonne staff organized and directed the tests of over 40 HEVs for engine emissions and SOC-corrected efficiency performance using Argonne-developed protocols at Chrysler, Ford, and EPA facilities during the 1995 Hybrid Electric Vehicle Challenge. Criteria pollutants, CO_2, and other relevant emissions, such as aldehydes, were measured in each of the three locations. Argonne staff developed improved HEV instrumentation to include measurement of compressed natural gas (CNG) temperature and pressure, improved engine on/off flags, and ground-fault detection.

Locomotive Diesel Engine Research CRADA with EMD and American Association of Railroads

1994-98 **DOE** *(Sponsor)*

Detailed engine performance, emissions, and combustion data were collected from a two-cylinder EMD 567 research engine with different oxygen-enriched intake air levels, different fuel flow rates, and injection timings. Argonne staff conducted the tests at ALI. Tests with a NO_x reduction catalyst and an air separation membrane are being planned for the current year.

EV/HEV Efficiency Testing

1994 **DOE** *(Sponsor)*

Argonne staff provided instrumentation and collected data from EV and HEV competitions in Arizona, Virginia, and California, which allowed efficiency measurements (watts/mile) to be taken from a wide range of production and prototype vehicles. Data were used for scoring and publications.

Evaluation of Oxygen Enrichment for Alternative-Fueled Vehicles

1994-95 **National Renewable Energy Laboratory** *(Sponsor)*

FTP tests were conducted on a flexible-fueled vehicle (Dodge Spirit), using Indolene and M-85 as fuels, to evaluate the emissions reduction potential of oxygen enrichment, especially during cold starts. Testing was performed at ALI using Argonne-provided specialized equipment and under Argonne supervision. Test data collected included speciated hydrocarbons, air toxics, and aldehydes, and second-by-second and bag emissions of NMHC/NMOG, CO, and NO_x. At Argonne, demonstration tests were conducted with an on-board prototype air-separation membrane.

Argonne's Engine Research Facility

HEV Emissions and Efficiency Testing

1994 **DOE and New York City** *(Sponsors)*

Argonne jointly tested HEVs for engine emissions and efficiency over FTP and New York City (NYC) cycles using a new Argonne-developed HEV test procedure and instrumentation with the NYC Department of Environmental Protection. Criteria pollutants, CO_2, and SOC-corrected kilowatt-hours of electricity were measured during the 1994 American Tour de Sol. Argonne also directed dynamometer testing of selected EVs for efficiency and range by using customized testing protocols.

HEV Efficiency and Emissions Testing

1994 **DOE and Saturn** *(Sponsors)*

Argonne developed a new HEV dynamometer test procedure and instrumentation to monitor energy flows in HEVs. Staff organized and directed the testing of over 40 HEVs for engine emissions and efficiency using Ford and EPA facilities during the 1994 Hybrid Electric Vehicle Challenge. Criteria pollutants, CO_2, and SOC-corrected kilowatt-hours of electricity were measured at both sites under Argonne direction. Staff pioneered the use of Global Positioning Systems (GPS)-linked data collection for measuring over-the-road performance. Data were used for scoring and publications.

FTP Emissions on Chevrolet Lumina

1994 **National Renewable Energy Laboratory** *(Sponsor)*

Complete emissions testing for criteria pollutants, including HC speciation, and estimates of smog-forming potential, using oxygen-enrichment technology for cars were performed at ALI under Argonne supervision.

NO_x Reduction with Monatomic Nitrogen

1993-96 **Argonne/LDRD** *(Sponsor)*

Bench-scale tests were conducted to evaluate the potential of monatomic nitrogen induced by pulsed plasma and continuous electric arc to reduce NO_x emissions from engine exhaust. Real-time exhaust from a four-stroke gasoline engine was tested to confirm the bench-scale results.

HEV and EV Efficiency Testing

1993 **DOE and Arizona Power Service** *(Sponsors)*

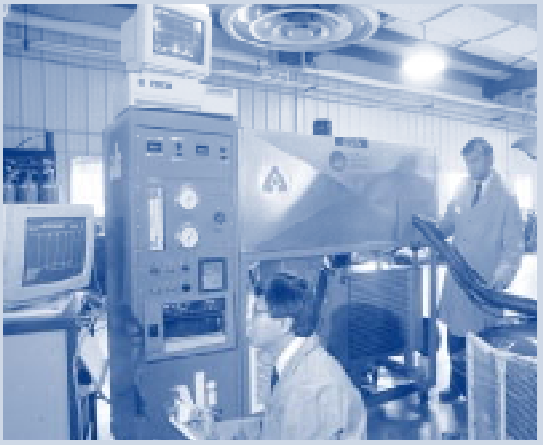
Using Argonne-developed instrumentation, Argonne staff measured efficiency (watts/mile) of over 30 EVs and HEVs during on-track competition in partnership with a major utility during the Arizona Power Service 500. Data were used for scoring and publications.

EV Efficiency and Range Testing

1993 **DOE** *(Sponsor)*

Argonne staff instrumented and tested over 30 EVs for efficiency (watts/mile) and range over closed course and for five days during over-the-road driving during the 1993 American Tour de Sol. Data were used for awards and publications.

Argonne engineers set up their equipment at AutoResearch Laboratories Inc., one of Argonne's research partners.



Performance and Emissions Improvements for Bus Diesel Engines

1993-95 **Regional Transit Authority, Chicago** *(Sponsor)*

Argonne conducted elaborate testing of DDC and Caterpillar engines for steady-state performance and emissions in a test cell at ALI and set up an analytical scheme to calculate gram/mile emissions values accurately in bus applications. This methodology avoids the cost of testing buses and could be used for any other application.

Dedicated CNG Efficiency and Emissions Testing

1993 **DOE and Texas** *(Sponsors)*

Argonne staff organized and directed engine emissions and efficiency testing (including criteria pollutants, HC speciation, modal emissions, CO_2, and catalyst efficiency) of over 25 dedicated CNG vehicles at EG&G, SWRI, and the Natural Gas Vehicle (NGV) Technology Center during the 1993 NGV Challenge. Results were analyzed and published by Argonne staff.

HEV Efficiency and Emissions Testing

1993 **DOE and Ford** *(Sponsors)*

Argonne staff organized and directed engine emissions and vehicle systems efficiency testing for 30 HEVs at the Ford Certification Laboratory in Dearborn, Michigan. Criteria pollutants, CO_2, and SOC-corrected kilowatt-hours of electricity were measured. Argonne staff developed and deployed new instrumentation for measuring energy consumption in HEVs and EVs.

CNG and LPG Engine Emissions and Efficiency Testing

1992 **DOE and EPA** *(Sponsors)*

Argonne staff directed the testing of over 20 dedicated CNG and liquefied natural gas (LNG) vehicles at EPA's Ann Arbor facilities for the 1992 NGV Challenge. Criteria pollutants, including HC speciation, modal emissions, and catalyst efficiency, were measured; Argonne analyzed the data and published a paper.

Electric Vehicle Testing

1992 **DOE** *(Sponsor)*

Argonne staff instrumented over 20 EVs and conducted standardized efficiency and range testing over a closed course to measure watts/mile efficiency during the American Tour de Sol. This testing was the first collection of these measurements on a wide-range of prototype EVs.

CNG and LPG Engine Emissions and Efficiency Testing

1991 **DOE and General Motors** *(Sponsors)*

Argonne staff organized and directed testing of over 20 dedicated CNG and LNG vehicles at the National Institute for Petroleum and Energy Research for criteria pollutants (including HC speciation and CO_2) for the first NGV Challenge. Data were used for scoring and publications.

M85 Engine Emissions and Efficiency Testing

1990 **DOE and EPA** *(Sponsors)*

Argonne staff directed testing of 12 M85 Chevrolet Corsicas for criteria pollutants and CO_2, including aldehydes and hydrocarbon speciation, at EPA's Ann Arbor facilities for the Methanol Challenge. Results included one of the cleanest vehicles ever tested at EPA and were used for several publications demonstrating the potential of alternative fuels.

Fuel Economy and Emissions Research on Heavy-Duty Diesel Engines

1988-94 **DOE Office of Industrial Technologies** *(Sponsor)*

Complex testing of a Caterpillar single-cylinder diesel engine to obtain performance, emissions (PM, NO_x, HC, and CO), cylinder pressure, and heat release rate data was performed at ALI. Using oxygen-enrichment technology, Argonne staff demonstrated that all performance and emissions parameters were significantly improved, except NO_x. Use of lower-grade fuels (Nos. 4 and 6) and water-emulsified fuels was also tested, with oxygen-enriched combustion air. Extensive follow-on testing of a Caterpillar 3406-truck engine confirmed results.

Fuel Economy Improvements for Ferry Boat Diesels

1988 **University of Washington** *(Sponsor)*

Argonne analyzed and made recommendations for large diesel engine power units and engine operation procedures to improve fuel economy by 15%. Several suggestions were adopted.

Fuel Injection System Modeling, Diesel and Coal/Water Slurry (CWS) Fuels

1986-87 **DOE Office of Industrial Technologies** *(Sponsor)*

Argonne staff developed a major computer code, FLUFIX, to analyze the performance of fuel injectors under very high shear rate conditions found in CWS fuel injection for conventional diesel engines.

Argonne received a patent for using monatomic nitrogen to reduce nitrogen oxide in engine exhaust.

Rankine Bottoming Cycle for Truck Diesel Engines

1986 **Cummins** *(Sponsor)*

Argonne staff performed a detailed analysis of fuel consumption benefits offered by a steam-bottoming cycle to recover exhaust gas energy from diesel engines. Previous DOE-sponsored bottoming-cycle projects involved organic fluids, which were considered to be impractical. Argonne found that a steam-bottoming cycle can save about 13% in fuel consumption, but the initial cost may be too high.

Performance and Emissions of a Coal/Water Slurry Diesel

1984-87 **DOE Office of Industrial Technologies** *(Sponsor)*

Argonne staff set up the emissions instrumentation for a single-cylinder Sulzer test engine at ALI using coal/water slurry fuel and collected and reported data on engine performance, emissions, and durability.

Sulzer Diesel Engine Data Collection and Analysis

1981-84 **DOE Office of Industrial Technologies** *(Sponsor)*

Argonne staff monitored the installation and operation of a diesel cogeneration unit at Hoffmann-LaRoche in New Jersey for DOE; Argonne collected engine performance and emissions data.

SELECTED PUBLICATIONS ON ENGINE AND EMISSIONS RESEARCH

Diesel Engine Research

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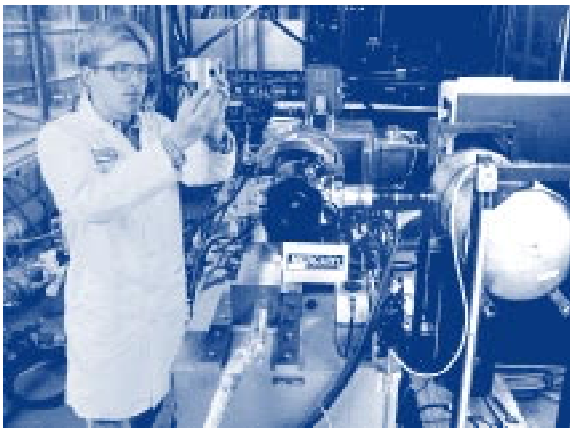

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