OAK RIDGE NATIONAL LABORATORY

MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Fiscal Year 2003 Transportation Program Highlights

January 2004

Compiled by
Kathi H. Vaughan

for the

FreedomCAR and Vehicle Technologies Program
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

OAK RIDGE NATIONAL LABORATORY
managed by
UT-Battelle, LLC
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

Fiscal Year 2003 Transportation Program Highlights

Richard E. Ziegler, Director
Edmund T. Grostick, Deputy Director

Page

Introduction

The Oak Ridge National Laboratory (ORNL) Transportation Program supports the mission of the Department of Energy, Office of Energy Efficiency and Renewable Energy, FreedomCAR and Vehicle Technologies Program (FCVT) through in-house and subcontracted research and development (R&D) activities. The ORNL Transportation Program also provides field technical management for DOE/EE in the materials technical area. The Program received approximately $41.5 million in new budget authority in FY 2003. Partners in industry and academia expended over $11 million in R&D subcontracts, many of them with substantive cost sharing. The Program supported over 190 full-time-equivalent ORNL technical staff members, and 2 National User Facilities.

This report is organized in two sections. The first section consists of brief summaries of progress during FY 2003 for ORNL R&D projects and field technical program management activities. The second section consists of detailed descriptions of noteworthy technical highlights and research results.

Project and Program Summaries

Advanced Power Electronics (Laura D. Marlino)

ORNL's Power Electronics and Electric Machinery Research Center conducts fundamental research, evaluates hardware, and assists in the technical direction of the DOE FCVT Power Electronics and Electric Machinery Program. In this role, ORNL serves on the FreedomCAR Electrical and Electronics Technical Team, evaluates proposals for DOE, and lends its technological expertise in the direction of projects and evaluation of developing technologies. ORNL also executes specific research projects for DOE. Numerous project reviews, technical reports, and papers have been published from these projects.

During FY 2003, ORNL conducted physical evaluations of prototypical hardware that resulted from five DOE prime contracts with industry for development of automotive electric motors and drives. All of the contracts were nearly complete at the end of FY 2003. ORNL has issued RFPs and is in the process of awarding contracts for the development of dc-dc power converters and motor controllers.

A new thrust of research addresses thermal management of the electric drive system, and resulted in a series of patents on new approaches. These technologies continue to be pursued at the request of the Electrical and Electronics Technical Team, with a new interest in development of demonstration hardware and subcontracts to broaden the research.

ORNL continued to develop fundamental advances in motor drives, dc-dc converters, and motors for automotive applications. This work resulted in newly developed, patented approaches to developing cost-effective and robust high-performance electric drives. An increased level of effort looked forward to the use of silicon carbide and other wide band-gap electronic devices and how to best apply this pending advancement in power switch technology that will likely be available for automotive applications in the next several years.

Automotive Lightweighting Materials (Philip S. Sklad)

The Automotive Lightweighting Materials Program supports FCVT by focusing on the development and validation of advanced lightweighting materials technologies to significantly reduce automotive vehicle body and chassis weight without compromising other attributes such as safety, performance, recyclability, and cost. ORNL provides overall field technical management of the program.

David Garman, DOE/EE Assistant Secretary, speaks at the TMAC dedication ceremony.

During 2003, installation of the Test Machine for Automotive Crashworthiness (TMAC) for Intermediate Rate Crush Studies was completed, and a dedication ceremony was held at the National Transportation Research Center. Distinguished guests included David Garman, Assistant Secretary for Energy Efficiency and Renewable Energy, Department of Energy; and Richard Jeryan of the Automotive Composites Consortium, U.S. Council for Automotive Research. This unique machine will permit, for the first time, progressive crush experiments at high force levels and constant intermediate velocities. The data obtained from the tests is critical for the development of predictive crash models.

Short electrode life is a barrier to the implementation of new light weight materials including galvanized steels and aluminum alloys into automotive applications. Oak Ridge National Laboratory in collaboration with Edison Welding Institute, DaimlerChrysler, Ford Motor Company, and General Motors, have developed a model to predict the deterioration of resistance spot welding electrodes through mechanical deformation and chemical attack. This will allows industry to evaluate standard electrode materials as well as new materials under practical industrial conditions. The methodologies will lead to extended life of the existing electrodes and development of new long life electrodes.

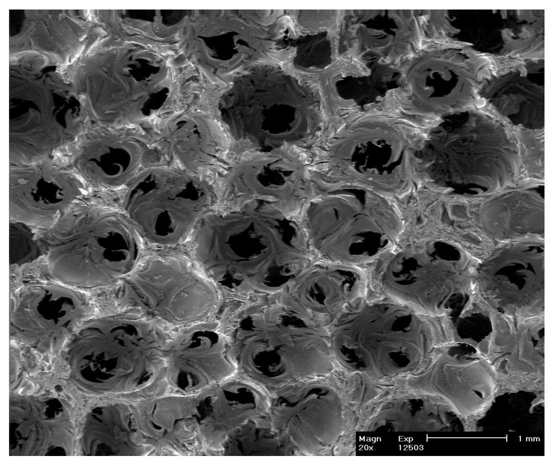
Significant advances were made in developing the technologies necessary to reduce the cost of carbon fiber to levels acceptable to industry, thereby enabling a cost effective potential reduction in vehicle weight of 50% to 60%. Scientific development of the technologies to convert textile grade PAN (polyacrylonitrile) into carbon fiber were completed. This technology alone, if the engineering development phase is completed, can reduce carbon fiber price from $7.00 per pound to less than $5.00 per pound. In addition, initial development of lignin-based precursors was concluded with a demonstration of a small composite made from carbon fibers produced from lignin. The next phase will consist of scaling up the technology to tow-size fiber bundles. This technology has the potential to reduce carbon fiber price to $3.00 to $4.00 per pound.

Microwave plasma technology for converting precursors into carbon fiber achieved line speeds of over 250 inches per minute, doubling the speed of conventional processing methods. A new unit was designed and built, which processes three to five tows simultaneously, as the final scale-up stage of the project.

The development of methodologies for assessing the long term durability of carbon fiber–reinforced thermoset materials was completed. In conjunction with industry partners, work is now ongoing to convert this methodology into industry standard design guidelines for using advanced composites. A candidate carbon fiber–reinforced thermoplastic system was selected for durability evaluation, which has now begun.

Automotive Propulsion Materials (David P. Stinton)

FY 2003 featured notable accomplishments in both the power electronics and combustion and aftertreatment materials program areas. Materials R&D in support of power electronics featured improved heat sinks fabricated from high conductivity graphite foam. Models were developed to better understand heat transfer in carbon foam and to reduce the cost of the carbon foam. Materials research supporting combustion engine and aftertreatment technologies led to the development of a particulate filter for small diesel engines that has a backpressure that is ten times lower than competitive products. Finally, a process was developed to fabricate fuel injectors with orifices of approximately 50 microns that significantly reduce particulate emissions.



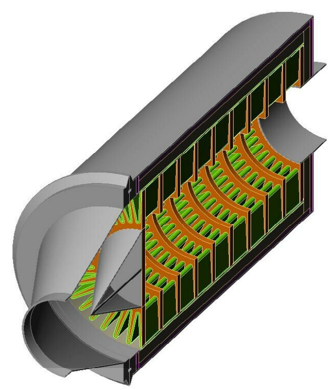
Graphite foam material developed at ORNL.

<u>Power Electronics</u>. High-power electronic components like power modules and inverters being developed for hybrid electric vehicles generate significantly more heat than conventional devices. Dissipation of the heat generated by these devices in hybrid electric vehicles requires an additional cooling loop and water-cooled heat sink to prevent overheating and failure of the devices. The increasing power requirements of electronic devices require that more sophisticated heat sinks be developed to keep the temperature of the electronics below about 120°C. High conductivity, high surface area carbon foam is an innovative new material that offers great potential for advanced heat sinks and heat spreaders; however, the high cost of the material is a concern.

An economic model was developed in FY 2003 for the process for fabricating high-conductivity carbon foam. More than 50 factors affecting foam cost were identified in this extensive study. The Excel-based model showed that the pitch precursor and graphitization step (temperature, time, furnace size, etc.) had the most dramatic effect on the cost of the foam. The model also provided insight into the sensitivity of expected pitch price to all of the key process and business parameters, and therefore served as a tool to guide further development and commercialization. Research efforts have been redirected to evaluate less costly pitch precursors and simpler graphitization steps.

A collaborative effort between the National Security Agency and ORNL has used high-conductivity carbon foam to dramatically increase the cooling capacity of the system. The lightweight carbon foam has a ligament thermal conductivity comparable to that of diamond wafers but has a surface area that is more than two orders of magnitude greater. When the diamond spreader was replaced by graphite foam, a power density of greater than 110 W/cm^2 was attained without overheating the system. The same technology has been used to develop a low-cost passive heat sink for power modules and inverters.

Advanced Combustion Engine and Aftertreatment Technologies. Industrial Ceramic Solutions (ICS), a small business located in Oak Ridge, Tennessee, has developed a pleated ceramic fiber filter cartridge to remove particulate emissions from the exhaust of small diesel engines that operate at relatively low exhaust temperatures (300°C or less). This cartridge removes greater than 95% of the diesel soot particles at a fraction of the backpressure of conventional wall-flow filters. Backpressure on a diesel engine is detrimental because it reduces the efficiency of the engine and increases the fuel consumption. The backpressure of the ICS fiber filter is one-tenth that of the extruded honeycomb filter product. In addition, the thermal mass of the ICS filter is one-third that of the honeycomb filter. Thus, it requires less costly auxiliary energy to achieve filter cleaning. These advantages can reduce the fuel consumption penalty from 15% down to 1%. The final advantage is the cost of the product in a high-volume market. This is a simple pleated design that is similar to millions of air and liquid filtration devices used around the world. It is manufactured by established processes on existing high-volume equipment.



"Wilson cylinder" configuration of ICS ceramic fiber diesel particulate filter.

ICS is entering product qualification programs with diesel engine suppliers in the United States and Europe. These suppliers require manufacturing capacity for millions of diesel particulate filter units per year. ICS is in final negotiations with a U.S. filter products company, New York Stock Exchange–listed with international sales, to license the technology for volume production. If the qualification tests are successful, it is likely that the low-cost ICS filter will be incorporated into a variety of systems that enable automakers to meet the more stringent emissions requirements in the United States in 2007, and in Japan and Europe in 2008.

Another method for reducing particulate emissions from diesel engines is to improve fuel atomization. This can be accomplished in a number of ways: increasing the fuel injection pressure, sophisticated control of the injection timing, and/or reducing the diameter of the orifices through which fuel is injected into the cylinder. Increasing the injection pressure is problematic because of safety concerns and the increased risk of cracking the injectors. Control systems—particularly those requiring specialized sensors for monitoring the combustion process—can add to the complexity and expense of the engine. Research has shown that the use of injectors with orifice diameters around 50 μm should result in significant reductions in particulate emissions; however, no processes are available for fabricating such fuel injectors.

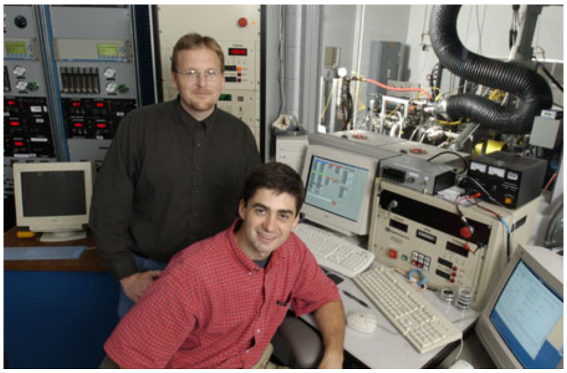
Typical diesel fuel injector nozzles.

Work conducted at Argonne National Laboratory (ANL) in FY 2003 demonstrated the feasibility of using electroless nickel plating to reduce injector orifice diameter of standard injectors from 200 μm to about 50 μm, by depositing thick, uniform layers of nickel plate along the interior surface of the injector orifice. Electroless nickel plating is a mature technology, but one which has not been used in this application before. It is highly scalable, and appears to be an economical technique for fabricating small-orifice injector nozzles. In addition to achieving major reductions in orifice diameter, ANL research has shown that electroless nickel deposition reduces surface roughness on the orifice interior. Changes in the plating bath chemistry have also been shown to vary the hardness of the nickel plate, suggesting the possibility of tailoring the hardness to increase cavitation erosion resistance. In addition, bench tests indicate that electroless nickel coatings are approximately 50% less susceptible to deposit formation than is the base metal of the injector.

Fuels, Engines, and Emissions Research (Ronald L. Graves)

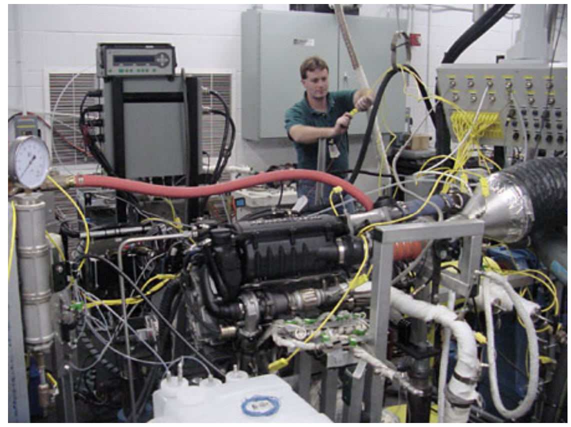
ORNL's Fuels, Engines, and Emissions Research Center (FEERC), located at the NTRC site, conducted R&D for multiple subprograms of the Office of FreedomCAR and Vehicle Technologies in 2003, including Advanced Combustion Engines, Fuels Utilization, and Systems. Strong industry collaboration in FEERC is evidenced by six active CRADAs in engine/emissions technology, plus a seventh CRADA being formed to start in FY 2004. Some of the CRADAs have resulted in unique research hardware being installed at FEERC. Informal collaborations are prevalent as well. The FEERC is a DOE National User Facility, and several user projects, both proprietary and non-proprietary, were conducted in 2003.

FEERC staff are highly engaged in supporting FreedomCAR and 21st Century Truck Partnership (21CTP) programmatic activities such the Advanced Combustion and Emission Control tech team, the Diesel Crosscut Team, and the 21CTP "Lab Council." In fuels utilization, FEERC staff co-chair three sub-teams of the Advanced Petroleum Based Fuels-Diesel Emission Control project and sit on the steering committee in partnership with NREL.



Robert Wagner, ORNL engineer, and Eric Nafziger, post-bachelors student, in the control room of Engine Test Cell No. 4, where studies of advanced combustion regimes are being conducted.

The FY 2003 efforts in Advanced Combustion Engines highlighted an orderly shift in some emphasis to engine fuel economy and advanced combustion regimes while still focusing on key remaining issues in emission controls. ORNL was invited to join 14 other organizations in a Memorandum of Understanding on Advanced Engine Combustion Research. Studies were initiated on how advanced combustion regimes might be exploited for inherent efficiency gains in addition to determining the emissions benefits. Exhaust species from low-temperature combustion were characterized in unprecedented detail with analytical tools developed at FEERC as well as via unique instruments brought to FEERC by other labs. Powerful capabilities in engine electronic control prototyping were exercised to characterize four methods of regenerating lean NOx traps (LNT). In the course of these experiments, a method of generating significant quantities of hydrogen in the exhaust was developed and confirmed in first-of-kind measurements using a diagnostic instrument unique to FEERC. CLEERS (cross-cut lean exhaust emission reduction simulation) activities continued with co-leadership by an industry champion and ORNL with strong participation from both auto and engine manufacturers. Catalyst suppliers became direct CLEERS "Focus Group" participants in 2003, a significant event in attaining the project objectives. New kinetic data on LNT materials have been developed at FEERC along with new understanding of the role of individual LNT constituents. Technical information is posted on a CLEERS website maintained by ORNL. Through detailed measurements of how LNTs use exhaust hydrocarbons, a method was identified to tailor the species to lessen the fuel penalty incurred during LNT regeneration. Improved understanding of urea decomposition processes and products at low exhaust temperatures was developed in a CRADA with USCAR. Low-temperature operation remains as perhaps the only *performance* barrier to this option for diesel NOx control.



Scott Sluder checks the research engine in Cell 4, where experiments are under way on low-temperature combustion and urea-SCR NOx aftertreatment.

In fuels utilization, ORNL participated in completing the studies of how fuel and lubricant constituents such as sulfur and phosphorous can degrade the functionality of emission control devices. An instrument and method to detect the sulfur-induced corrosion in the EGR systems of new engines was transferred to industry. At the suggestion of the Diesel Crosscut Team, development of rapid aging methods for LNTs was started, co-sponsored by the Advanced Engines team. ORNL also assisted in characterizing the unregulated emissions as influenced by fuel and aftertreatment technology, and are finding generally low levels of "toxics" in emerging systems studied to date. New tasks were started on understanding how fuel properties affect advanced combustion regimes. Initial results confirmed the expectation that new processes such as low temperature combustion were impacted by notable shifts in fuel properties. New data were also generated on how fuels might be tailored to enhance NOx aftertreatment performance.

R&D projects for the OFCVT Systems Team and others included a second round of emissions measurements from idling trucks in collaboration with EPA and the Army Aberdeen Test Center. A new method for rapid assessment of exhaust toxicology was evaluated on gasoline and diesel vehicles. Generally it is being found that new engine and emission technologies are so "clean" that toxicity is not readily detectable.

Heavy Vehicle Propulsion Materials (D. Ray Johnson)

Advanced materials are an enabling technology for fuel-efficient heavy-vehicle engines. ORNL provides field technical management for the Heavy Vehicle Propulsion Materials project, including technical progress monitoring and coordination of activities both internally and for the national program. The project is organized around technology issues relating to fuel systems; exhaust aftertreatment; air handling, hot section, and structural components; and standards.

<u>Fuel systems.</u> Materials and manufacturing technology were developed for a new generation of wear- and scuff-resistant fuel system components. R&D partners included Cummins Engine Co., CoorsTEC, ORNL, Southern Illinois University at Carbondale, and University of Colorado. The material developed is a cermet made of a nickel aluminide (NiAl) matrix and titanium carbide (TiC) ceramic phase. The material can be engineered to match the coefficient of thermal expansion of steel. Cummins provided the design and materials requirements and performed prototype testing. CoorsTEC, a ceramic manufacturer and suppliers of Cummins' zirconia ceramic components, developed the cermet manufacturing technology. ORNL invented the NiAl–TiC cermet

and performed much of the cermet processing and microstructure development. The University of Colorado developed cost-effective processes to synthesize powders for manufacture of the material. Southern Illinois University at Carbondale developed two low-cost manufacturing processes for the cermet material: low-pressure injection molding and continuous sintering in a belt furnace.

A second fuel system task demonstrated the feasibility of piezoelectric actuators for heavy-duty diesel engine fuel injectors. Detroit Diesel, Inc. (DDC) completed a project that developed technical requirements for a valve actuator system including advanced piezoelectric materials to enable faster, more precise control of the injection rate characteristics of a heavy-duty diesel injector. ORNL and Wayne State University provided materials development and testing for the project. DDC found that the piezoelectric stack is a viable actuation device, providing substantially faster response times than the prevailing solenoid technology. In addition, commercially available piezoelectric stacks were determined to have adequate material properties and technical characteristics for fuel injection.

<u>Exhaust aftertreatment.</u> Accomplishments in 2003 include significant progress in a collaborative program between ORNL and Ford Motor Co. to facilitate deployment of a NOx trap for lean diesel or gasoline exhaust. Tasks include investigating materials issues related to deterioration of NOx trap performance resulting from thermal and sulfation-desulfation cycles, and investigating materials that are robust under lean NOx trap operating conditions, including synthesis of new materials.

Research conducted at the High Temperature Materials Laboratory focused on the development and utilization of new capabilities and techniques for ultra-high resolution transmission electron microscopy to characterize the microstructures of catalytic materials for reduction of NOx emissions in diesel and automotive exhaust systems. This research aims to relate the effects of reaction conditions on morphological changes of heavy metal species on “real” catalyst support materials, typically oxides.

Exhaust aftertreatment materials projects at both Caterpillar, Inc., and Cummins Engine Co. are significant in that they represent a departure from an earlier culture in which the diesel engine companies did not actively participate in the development of catalyst materials, instead relying heavily on catalyst manufacturers to provide the needed technologies. These diesel engine manufacturers are actively collaborating with catalyst suppliers in the development of improved catalyst materials and are contributing to the fundamental understanding of catalyst performance that is important to both suppliers and users of catalyst systems.

Ford Motor Co. and ORNL are collaborating on the development of a NOx sensor that can be used in on-board exhaust remediation systems. Prototype sensing elements are fabricated by patterning electronically conductive and catalytic layers onto oxygen-ion conducting substrates. The sensing elements are then characterized for NOx response, oxygen sensitivity, and response time. These results, along with microstructural characterization, should point to the correct combination of materials chemistry, materials processing, and sensor design required for the desired sensor performance

Materials for air handling, hot section, and structural applications. Caterpillar began a new project in 2003 to design and fabricate a cost-competitive diesel engine turbocharger using lightweight titanium materials to reduce fuel consumption and transient emissions. Caterpillar has designed a series turbocharger to replace the current two-turbocharger system for the C15 engine platform. The series turbocharger consists of one turbo wheel and two compressor wheels attached to a single rotating drive shaft. Titanium aluminide will be used for the turbo wheel, and one of the compressor wheels will be made from a titanium alloy.

In a related project, Dynamet Technologies, Inc., is developing low-cost Ti-6Al-4V billet feedstock using a blend of titanium and alloy powders and inexpensive Ti-6Al-4V machine turnings. Dynamet will evaluate this low-cost titanium alloy feedstock as starting billet material for casting, forging and extrusion operations.

Caterpillar and ORNL won an R&D 100 award for the development of CF8C-Plus cast stainless steel. The new, high-temperature stainless steel may have near-term applications in diesel engine exhaust manifolds and turbocharger housings.

Caterpillar, in collaboration with Argonne National Laboratory and ORNL, has a project to design and fabricate prototype engine valves from silicon nitride and titanium aluminide materials. The successful demonstration of engine valves fabricated from silicon nitride and titanium aluminide materials is anticipated to extend the component service lifetimes by as much as 200% over current valve materials. In addition, these lightweight materials will enable the future design of a camless engine that will permit greater control over the combustion process, improving engine performance while reducing emissions. Caterpillar is also developing innovative approaches to thermal barrier and wear-resistant coatings for engines. The durability of thermal sprayed coatings, particularly thermal barrier coatings, remains as the major technical challenge to their implementation in new engine designs. New approaches to coating design and fabrication are being developed to aid in overcoming this technical hurdle. Specific objectives are laser technology of surface dimpling, cleaning and laser-assisted spraying to enhance adherence and increase coating strength; development of phosphate-bonded composites for thermal management coatings; and evaluation of quasicrystalline materials as potential thermal barrier and wear coatings.

Materials and testing standards. FCVT participates in the International Energy Agency (IEA) "Implementing Agreement For A Programme Of Research And Development On Advanced Materials For Transportation Applications." Annex III, approved in July 2002, is under way, and consists of two tasks on contact reliability of advanced engine materials including structural ceramics, composites, and nanostructured friction/wear coatings. The Implementing Agreement Executive Committee plans to invite the United Kingdom to join the agreement due their interest in Annex III. In addition, preliminary discussions have been held with Canada concerning the initiation of a new Annex on lightweighting of materials.

A new activity under the IEA program is being developed by the National Institute of Standards and Technology (NIST). The objectives of this new effort are to

1. organize an international cooperative research program on an integrated surface modification technology under the auspices of the IEA,
2. design and identify surface features and patterns that can achieve friction reduction and enhanced durability for heavy duty diesel engine components,
3. develop understanding and appropriate models to explain the texturing effects on frictional characteristics,
4. develop appropriate thin films and coatings to achieve synergistic and complementary relationship with texturing to enhance performance, and
5. discover and develop surface chemistry for protecting the films and coatings which work in synergy with the textures.

NIST also leads a project to develop standard testing methods for advanced materials, primarily ceramics. Standard Reference Materials are created to support the test methods and materials specifications. In FY 2003, Standard Reference Material (SRM) 2831 for Vickers Hardness of Ceramics and Hard Metals was finished. This SRM complements ASTM and ISO test methods standards for Vickers hardness of hard materials and new material specifications standards such as ASTM F 2094 for silicon nitride for ball bearings.

High Strength Weight Reduction Materials (Philip S. Sklad)

The High Strength Weight Reduction Materials Program supports FCVT by developing materials and materials processing technologies that contribute to reduced parasitic energy losses due to the weight of heavy vehicles, without reducing vehicle functionality, durability, reliability, or safety; and to achieve this goal in a cost-effective manner. ORNL provides overall field technical management for monitoring technical progress of projects, coordinating activities both internally and for the national program, and interacting with other national laboratories, industry, and academia.

During 2003, ORNL issued a Request for Proposals for “Development of Technologies for Reduction in Weight of Class 7 & 8 Tractor Trailers.” After review and ranking by an evaluation team, two proposals were selected to receive awards and contracts have been initiated.

The use of friction stir processing technology to improve the surface properties of cast aluminum alloys is being investigated in collaboration with Ford Motor Company and South Dakota School of Mines. Results of the work demonstrate that friction stir processing can dramatically refine the size of particulate phases in aluminum A319 and distribute them more uniformly. The processing also closes open porosity in the treated volume. The ductility and fatigue life of cast materials was significantly increased. The surface property improvements could have important implications for the manufacturing of critical cast aluminum components for a wide variety of automotive applications.

The design phases were completed in three subcontracts for development of carbon fiber–reinforced composite cab, body and chassis structures. Those projects have resulted in composite tie rods making an early entry into the commercial market, and the development of the first truly low-cost carbon fiber sheet molding compound, which will have wide applicability. One project initially redesigned a component for manufacture using composite materials. The component redesign was accepted but manufactured using aluminum, which saved about half the weight of the original design, was easier to manufacture, and met cost targets.

High Temperature Materials Laboratory (Arvid E. Pasto)

The HTML User Program staff performed work on 97 open projects from the previous year and initiated another 72 in FY 2003. The number of User Agreements between user institutions and ORNL increased dramatically, opening the door to future research projects, with 44 of the 50 new agreements being with industrial concerns. New projects of note involved numerous investigations of improved or advanced engine components or materials, improved processes for manufacturing automotive materials and components, and basic investigations into structural materials.

In advance engine components and materials, projects included one on ceramic valves from Caterpillar, Inc., one with Cummins Engine Company on grinding of steel and zirconia (which also strongly relates to improved manufacturing processes), one on development of novel connecting rods with Machine and Design Technologies, Inc., and several on newly emerging amorphous alloys. Projects in manufacturing processes included one with the University of Michigan on friction stir welding, one with the University of Alabama-Birmingham on roll-casting of aluminum alloys, and one on magnetic materials made by dynamic magnetic compaction.

Basic automotive-related materials projects included a study of lubricant additive effects on surfaces of bearings with Timken, deformation of aluminum and magnesium alloys by equal channel angular processing with the University of Tennessee, and a study of grain boundary segregation in titanium alloys with ALLVAC-Titanium Forged Products.

Other projects involved study of various mechanical and thermal effects and behaviors, studies of microstructures, crystal structures, stresses in components, and tribological effects.

Construction began on the GPP-funded Advanced Materials Characterization Laboratory (AMCL), with work progressing nicely through the year, remaining within budget and on schedule. The building is expected to be completed in February 2004, and ready for occupation in March. Meanwhile, the major planned occupant of AMCL, the Aberration-Corrected Electron Microscope (ACEM), is under construction at JEOL in Japan. It is to be completed in February, and delivered to ORNL by April. HTML staff will travel to Japan to put the ACEM through its acceptance tests before shipping.

Collaboration with the Spallation Neutron Source (SNS) staff at ORNL continued, in an effort to participate in construction and operation of the "engineering beamline" diffraction instrument called "VULCAN." The goal is to make this instrument widely and quickly available to industrial, academic, and governmental users, through the HTML User Program, when it goes on-line in FY 2006 or 2007.

National Transportation Research Center (Richard E. Ziegler)

Consolidation of Transportation Program research staff at the National Transportation Research Center was completed in late FY 2003, with staff from ORNL's Center for Transportation Analysis (CTA) moving into the building. CTA staff perform work for a variety of sponsors, including DOE/EE FCVT and Hydrogen, Fuel Cells and Infrastructure Technologies programs; federal and state Departments of Transportation; Federal Aviation Administration; and Department of Defense.

ORNL and the University of Tennessee succeeded in filling a joint appointment position to serve as NTRC Director and UT Condra Chair of Excellence in Automotive Systems. Dr. Steve Arnette, formerly of Sverdrup Technologies, will be responsible for increasing collaborations between the University and the NTRC. He is currently spending most of his time becoming acquainted with the extensive research and development capabilities resident at the NTRC, as well as complementary capabilities and operational considerations at both the University and ORNL.

Planning began for construction of an annex to the NTRC. The annex would house the Heavy Vehicle Safety Research Center and expanded facilities for the Fuels, Engines and Emissions Research Center (FEERC). The facilities envisioned for the FEERC would provide the capability to perform research on large truck (Class 8 and greater) and off-road engines. A distinguishing feature would be the ability to perform full pass dilution of the exhaust streams from compression ignition and spark-ignited engines ranging from 800 to 1250 horsepower. The annex would also allow the FEERC to perform R&D on hydrogen- and natural gas–fueled vehicle power plants, and hybrid variations including fuel cells.

Installation of a United Technologies Corporation stationary (phosphoric acid) fuel cell was completed. The fuel cell provides about 200 kW to the NTRC, approximately one-third of the building's power needs, at a resource efficiency of almost 60% year-round. Hot water produced by the fuel cell is used to control the building temperature. The fuel cell is instrumented to gather performance data for ORNL’s Cooling, Heating, and Power Group as part of a project to evaluate the performance of stationary fuel cells in working environments. The fuel cell is also being used as a test bed for a reverse power relay that prevents power flow from the fuel cell to the power grid, in a collaborative effort between ORNL, the Lenoir City Utility Board, Tennessee Valley Authority, and EPRI-PEAC.

United Technologies fuel cell installed at the NTRC provides building power and temperature control.

During FY 2003, 11 external organizations inquired about establishing user agreements with the NTRC. Six of those inquiries were either determined to be not suitable for user agreements (primarily due to the non-competition requirement) or are still under discussion. Five of the inquiries resulted in signed user agreements and four completed user projects. Three projects were performed in the Fuels, Engines and Emissions Research Center, and one in the Power Electronics and Electric Machinery Research Center.

The ORNL Research Business Management Division has calculated the FY 2003 cost savings derived from housing researchers at the NTRC instead of on the main ORNL campus to be approximately $974,200, for a cumulative savings (FY 2002–2003) of approximately $1,946,700.

Transportation Analysis, Modeling and Information (David L. Greene)

Three major studies were completed in 2003: an analysis of the likely transition from conventional to unconventional oil resources, market-based incentives as alternatives to fuel economy standards, and a study of alternative voluntary fuel economy standards.

Running Out of and Into Oil: Analyzing Global Oil Depletion and Transition through 2050. This project carried out a risk analysis of the peaking of world conventional oil production and the likely transition to unconventional oil resources such as oil sands, heavy oil and shale oil. Estimates of world oil resources by the U.S. Geological Survey (USGS), the International Institute for Applied Systems Analysis (IIASA), the World Energy Council (WEC), and Dr. C. Campbell provided alternative views of ultimate world oil resources. Global energy scenarios created by IIASA and WEC provided the context for the risk analysis. A model of oil resource depletion and expansion for 12 world regions was combined with a market equilibrium model of conventional and unconventional oil supply and demand. The analysis did not make use of Hubbert curves. Key variables such as the quantity of undiscovered oil and rates of technological progress were treated as probability distributions, rather than constants. Analyses based on the USGS and IIASA resource assessments indicate that conventional oil production outside the Middle East is likely to peak sometime between 2010 and 2030. Even if oil production does not peak before 2020, output of conventional oil is likely to increase at a substantially slower rate. Analysis based on data produced by Campbell indicated that the peak of non-Middle East production will occur before 2010. Once world conventional oil production peaks, first oil sands and heavy oil from Canada, Venezuela and Russia, and later shale oil from the United States must expand rapidly if total world oil consumption is to continue to increase. The analysis was documented in an ORNL-TM and a peer-reviewed paper to be presented at the 2004 Annual Meetings of the Transportation Research Board.

Feebates, Rebates and Gas-guzzler Taxes: A Study of Incentives for Increased Fuel Economy. Feebates are a market-based alternative to fuel economy standards. Vehicles with fuel consumption rates above a "pivot point" pay fees, while vehicles below receive rebates. By choice of pivot points, feebate systems can be made revenue neutral. This study re-examined feebates using recent data, assessed how the undervaluing of fuel economy by consumers might affect their efficacy, tested sensitivity to the cost of fuel economy technology and price elasticities of vehicle demand, and added assessments of gas-guzzler taxes or rebates alone. It is estimated that a feebate rate of $500 per 0.01 gallon per mile (GPM) would produce a 16% increase in fuel economy, while a $1,000 per 0.01 GPM would result in a 29% increase, even if consumers count only the first 3 years of fuel savings. Unit sales decline by about 0.5%, consumers' surplus decreases, but revenues increase because the added value of fuel economy technologies outweighs the decrease in sales. In all cases, the vast majority of fuel economy increase is due to adoption of fuel economy technologies rather than shifts in sales. Reductions in U.S. oil use and carbon dioxide emissions have also been estimated and are significant. The results of the study were described in a peer-reviewed paper accepted for publication in *Energy Policy*.

Analysis of the Monetary Costs and Benefits, and Impacts on Manufacturers of Alternative Voluntary Standards. The success or failure of a voluntary standard will depend on both its economic practicability and its fairness to manufacturers. Practicability depends on the balance between the cost of increasing fuel economy and consumers' willingness to pay for fuel economy improvements. Fairness requires maintaining a level playing field: not altering the competitive positions of manufacturers. This study assessed the economic practicability and differential impacts on manufacturers of different levels and forms of voluntary fuel economy standards. Its goal was to discover what range of fuel economy improvement may be feasible and what forms of voluntary standards are most likely to be acceptable. It was assumed that voluntary standards will be phased in gradually, and will have their full effect in the 2010 to 2015 time period.

Two levels of fuel economy improvement (20% and 33%) and three metrics (corporate average miles per gallon, uniform percentage increase, and a weight-based formula) were assessed, along with various alternative structures for establishing targets (industry-wide, manufacturer-specific, and so forth.). Several additional analyses were carried out to test the sensitivity of results to key assumptions.

Given the reference assumptions about how customers will value fuel economy gains and our estimates of the cost of increasing it, a 20% increase in miles per gallon is below the level that provides the greatest net value to car buyers over the full life of the vehicle. This result is dependent on a number of critical assumptions, however, not the least of which is that vehicle performance and sales mix remain constant. For most manufacturers, the 33% increase requirement was above the level that provides the greatest net value to car buyers, again given our reference technology cost functions.

The results of this analysis were included in a report published by Argonne National Laboratory and in a peer-reviewed article published in the *Transportation Research Record*.