

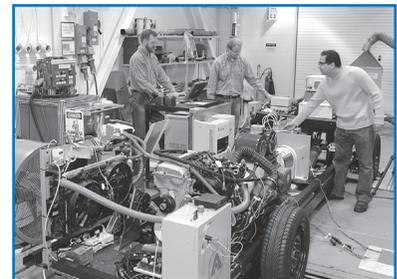
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News From Argonne's Transportation Technology R&D Center
www.transportation.anl.gov

▶ VIEWPOINT

Diversity of Choices: Key to Improving Transportation Energy Efficiency

Plug-in hybrid electric vehicles (PHEVs) offer the possibility of considerably improved fuel efficiency over today's hybrid vehicles, especially if they offer fuel-flexibility and are properly matched to the intended use scenario. The U.S. Department of Energy is expanding its PHEV research efforts with an eye to advancing the technologies needed to make these vehicles commercially viable. [Page 2](#)



▶ RESEARCH REVIEWS

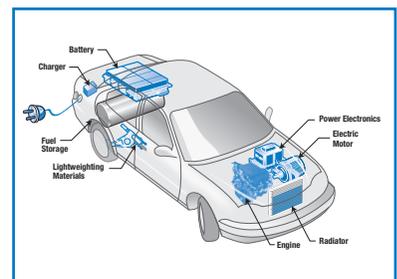
Argonne Leading DOE's Plug-In Hybrid Technology Evaluation Effort

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Electric Power Research Institute and Argonne Agree to Collaboratively Assess Commercial Viability of Plug-In Hybrid Electric Vehicles

The Electric Power Research Institute (EPRI) and Argonne National Laboratory, two of the nation's premier research organizations, have entered into a three-year collaborative agreement to conduct the next level of analysis of plug-in hybrid electric vehicles (PHEVs) aimed at assessing the commercial feasibility of this technology. [Page 6](#)



Lithium-ion Batteries Could Hold the Key to 100-MPG Hybrids

Lithium-ion batteries are a promising alternative to the nickel metal hydride batteries used in current-generation HEVs. Lithium-ion batteries pack more power and energy into a smaller battery package. But there's work to do before lithium-ion batteries are ready for commercialization in this market. [Page 5](#)

New Version of PSAT Released

The developers of Argonne's award-winning Powertrain System Analysis Toolkit (PSAT) have announced that a new version of PSAT is now available for licensing and downloading. PSAT is the U.S. Department of Energy's (DOE's) FreedomCAR and Fuel Partnership Program's primary vehicle simulation tool. [Page 6](#)



▶ FASTRAX [Page 7](#)

▶ PUTTING ARGONNE'S RESOURCES TO WORK FOR YOU [Page 8](#)



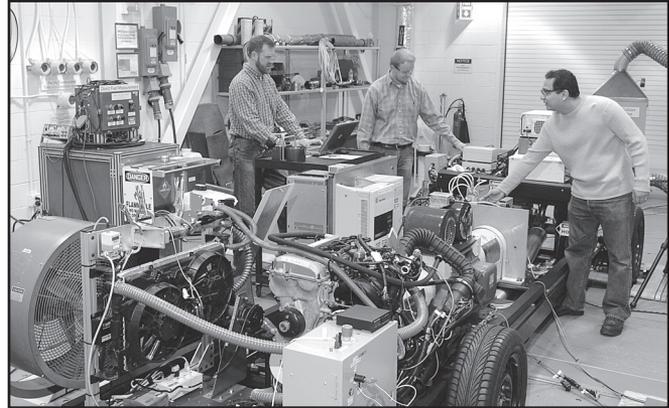
Diversity of Choices: Key to Improving Transportation Energy Efficiency

The U.S. Department of Energy (DOE) has identified plug-in hybrid electric vehicles (PHEVs) as having the potential to dramatically transform the light-duty vehicle sector to be much less dependent on petroleum, a key goal in DOE's strategic plans. As a consequence, says Lee Slezak of DOE's FreedomCAR and Vehicle Technologies Program, DOE is investing in PHEV research, in addition to other transportation technologies. Because Argonne National Laboratory possesses specialized staff expertise and technical capabilities, DOE has asked Argonne to assume a leading role in the Department's PHEV research efforts, particularly in the areas of analysis and evaluation of components, power electronics, energy storage, and vehicle technologies.

According to Slezak, "PHEVs offer the possibility of considerably improved fuel efficiency over today's hybrid vehicles, especially if they offer fuel-flexibility and are properly matched to the intended use scenario. They also produce fewer emissions in traffic and when operating at low speeds. Although the use of PHEVs would increase electrical demand, that increase could actually be beneficial, because the increased demand would typically occur at night, during utility companies' off-peak hours. This would allow the utilities to better balance their production loads, leading to improved operating efficiencies. Also, depending on economic and political factors at any given time, PHEVs could very well play an important role in reducing oil imports, which is, of course, an important DOE goal."

Slezak is quick to point out that, as with any new technology, there are hurdles to overcome before PHEVs can be considered commercially viable. "First, there is the concern about onboard storage. PHEVs require very different batteries than those used in today's hybrid vehicles. DOE's research is focusing on lithium battery chemistries in an effort to increase reliability and performance, while also reducing cost and size. Second, the cost of components such as power electronics, inverters, and controllers must be reduced in order to produce a faster payback period for PHEV buyers. And third, there is a dearth of information about PHEVs — as yet, there are no agreed-upon test and evaluation procedures for PHEVs. Argonne will be working together with the National Renewable Energy Laboratory and Idaho National Laboratory to address these issues," he says.

Slezak explains that there are other aspects to DOE's information-gathering mission as well. Manufacturers need to understand where the likely shortcomings in PHEV operation will occur, so they can make good engineering decisions as they design and produce their PHEV offerings. At the same time, consumers need to be educated to have realistic expectations



Argonne's Mobile Automotive Technology Testbed can be equipped to test the wide range of vehicle and fuel configurations that will likely factor into our nation's future transportation technology mix.

and to analyze their driving patterns carefully before making a vehicle purchase decision. Good analysis and research will enable buyers to choose vehicles that best meet their needs while enabling them to consume less fuel, all the while minimizing the payback period for the increased purchase price. Because that information does not yet exist for PHEVs, DOE will play an important role in developing it.

Slezak stresses that DOE is developing PHEV research and development plans very carefully to ensure that good processes are in place to promote success. This involves working closely with industrial partners and other government agencies to develop the right assessment and analytical procedures and identify critical decision points along the way. "If research efforts proceed smoothly, DOE envisions that PHEVs with limited electric range could be commercially available within the next two to three years. These initial PHEVs would likely have a cumulative electric driving range of 10 to 20 miles per charge at driving speeds of up to 35 miles per hour. Within six years, we anticipate the availability of PHEVs with a cumulative electric driving range of 30 to 40 miles per charge at similar driving speeds," he says.

Most important, continues Slezak, "As with all of the vehicle technologies DOE researches, it is important to recognize that there is no single best solution to America's transportation challenges. We need to develop a diverse set of technology options from which vehicle operators can choose, so they can select a clean, efficient vehicle that best meets their needs at the lowest possible cost."

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Argonne Leading DOE's Plug-In Hybrid Technology Evaluation Effort

The U.S. Department of Energy's (DOE's) FreedomCAR and Vehicle Technologies Program recently designated Argonne National Laboratory as DOE's lead national laboratory for the simulation, validation, and laboratory evaluation of plug-in hybrid electric vehicles (PHEVs) and the advanced technologies required for these vehicles.

A plug-in hybrid electric vehicle is similar to the hybrid electric vehicles (HEVs) on the market today, but with a larger battery that is charged both by the vehicle's gasoline engine and from plugging into a standard 110 V electrical outlet for a few hours each day. PHEVs and HEVs both use battery-powered motors and gasoline-powered engines for high fuel efficiency, but PHEVs can further reduce fuel usage by employing electrical energy captured through daily charging.

Argonne experts estimate that a PHEV could get more than 100 miles per gallon while the vehicle runs primarily on the battery — compared to the 30 to 55 miles per gallon that most of today's HEVs achieve — at a charging cost that's equivalent to roughly \$1 a gallon. Commuters who drive less than 20 miles a day might be able to drive a PHEV exclusively with its electric motor for their daily commutes.

While the PHEV technology shows promise, many broad energy and environmental considerations must be examined before PHEVs become widely available. For example, while a PHEV might cost less to drive than a gasoline-powered vehicle, it would draw power from the electrical grid when charging. Virtually all electricity in the United States today comes from domestic energy sources, and in some areas, much of that electricity comes from coal-burning power-generation plants. The energy needed to extract and transport the coal, as well as the environmental considerations associated with burning the coal, are all part of the overall cost of using plug-in technology. These issues could decrease in importance as the amount of renewable energy in the electricity mix increases. Other significant technical barriers to commercialization of PHEV technology include cost, battery size and performance, durability, and safety.

Cost

PHEVs require additional, expensive components — such as very large, heavy, and costly batteries — to provide adequate vehicle range. Also, power electronics must become smaller, simpler, and less expensive. The U.S. Department of Energy has determined that to be commercially viable, a hybrid technology vehicle must repay its extra upfront cost in the form of fuel savings within three years of the initial purchase in order to achieve widespread acceptance.



Battery Size and Performance

PHEV batteries must be compact in size, and offer high energy, large storage capacity, and the ability to support both deep and shallow discharge/charge cycles. With today's technology, a battery that's powerful and durable enough to power a PHEV's electric motor takes up more space than many vehicle makers or consumers are willing to sacrifice. In addition to the space occupied by the battery itself, there is also space on top of and around the battery that for safety reasons cannot be used. Old batteries must be recycled, and no one yet knows how much that recycling will cost on a per-vehicle basis once all transport, processing, and disposal costs are considered.

Durability

If you own any of today's high-tech rechargeable-battery-powered devices, such as MP3 players, PDAs or cell phones, you probably understand this problem firsthand. A battery small enough to meet the device's form factor and power requirements requires frequent recharging, and over time, it loses its ability to take and hold a new charge. Eventually, the battery must be replaced. In a car, however, consumers would expect the battery to last the life of the vehicle.

Safety

Any battery is potentially unsafe when mishandled or subjected to trauma such as physical blows, extremely high temperatures, or fire. Consequently, a vehicle that is safe under normal conditions requires a great deal of testing to determine its safety in a crash or fire. New battery technologies will require extensive testing before they are deemed suitable for in-vehicle use. Emergency responders must also learn how to handle new vehicle battery technologies safely in the event of a crash or fire.

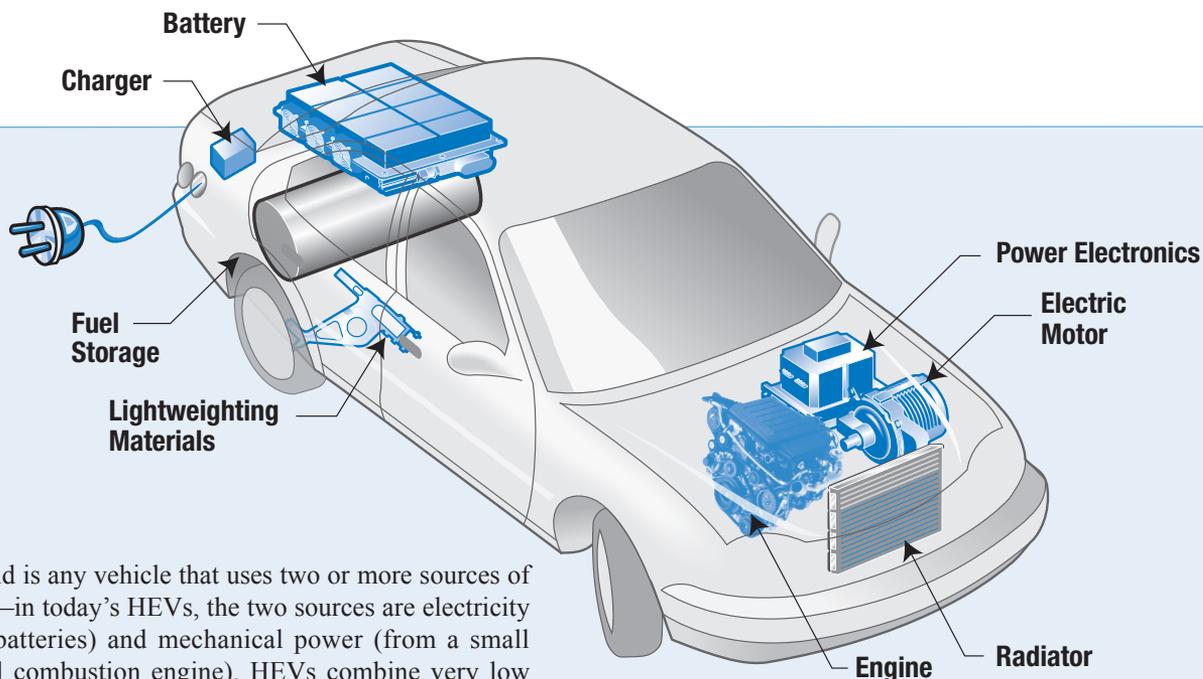
To address these issues and others, the U.S. Department of Energy's FreedomCAR and Vehicle Technologies Program is funding research in a variety of technical areas specific to PHEVs, including:

- Hardware-in-the-loop analysis
- Modeling & simulation
- Research and development for critical components such as batteries, motors and power electronics
- Component/subsystem testing and validation
- System and interface control development
- Vehicle testing and validation

Working together with researchers from Idaho National Laboratory, Argonne researchers are focusing their efforts in all of these areas to assess the technical, economic, and environmental viability of PHEV technology.

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What's a Hybrid Electric Vehicle?



A hybrid is any vehicle that uses two or more sources of power—in today’s HEVs, the two sources are electricity (from batteries) and mechanical power (from a small internal combustion engine). HEVs combine very low emissions with the power and range of gasoline vehicles. They also offer up to 30 miles more per gallon, perform as well as or better than, and are just as safe as any comparable gasoline-powered car.

How Does it Work?

When engine demand is low, such as when starting, traveling at a light load, or stopping, an HEV is driven only by its electric motor, using battery power. During normal travel, the gasoline engine engages as needed to drive the wheels and/or recharge the battery.

At full acceleration, the battery adds its power to the mix, which provides a very smooth, powerful response. When decelerating or braking, the regenerative braking system acts as a generator to help recharge the battery.

The engine shuts off when the car is idling or if engine demand is low. The gasoline engine runs only as needed to recharge the battery or run the air conditioner, which is why an HEV never has to be plugged in for recharging.

The HEV of the Future

In the future, an advanced hybrid, or plug-in hybrid electric vehicle, could be plugged in at night, using off-peak electricity, to “top off” the car’s higher energy content lithium-ion batteries. This would extend the car’s range and offer more than 100 miles per gallon of gasoline.

What is a PHEV and How Does it Work?

A plug-in hybrid electric vehicle (PHEV) is part electric vehicle and part gasoline vehicle. The difference between a PHEV and the hybrid electric vehicles (HEVs) you can buy today lies in how they charge their batteries.

A PHEV is similar to an HEV, but it has a larger battery that can be fully charged by plugging into a standard 110 V electrical outlet for a few hours each day. When the battery runs low, the vehicle acts like today’s conventional hybrids with high fuel economy, but without using any more energy originating from “the plug.”

Lithium-ion Batteries Could Hold the Key to 100-MPG Hybrids

Argonne National Laboratory is using its expertise as a top lithium-ion battery R&D organization to help the Department of Energy advance technology for plug-in hybrids — hybrid electric vehicles that let consumers recharge batteries by plugging into a wall outlet.

Hybrid electric vehicles (HEVs) are no longer cars of the future. As the price of gasoline has gone up, so has the demand for HEVs. Interest is growing in HEVs that can recharge from wall-plug energy (plug-in HEVs, or PHEVs) because of their high fuel economy (up to 100 miles per gallon) and the ability take advantage of off-peak electricity, which offers power generation efficiency and environmental benefits.

There are substantial technical challenges associated with PHEVs. Although they can be built today (concept prototypes include General Motors' Chevrolet Volt car, DaimlerChrysler's Sprinter van, Hymotion's plug-in retrofit for Toyota's Prius automobile, Ford's Escape sport utility vehicle [SUV], and Mercury's Mariner SUV hybrids), current battery technology is a "show stopper" in terms of energy, life, and cost.

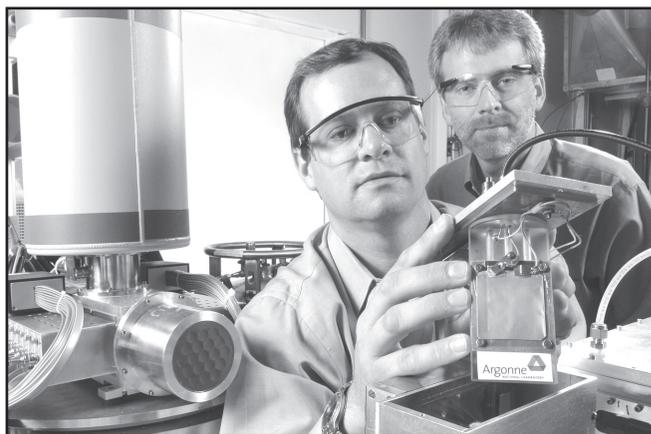
Lithium-ion Batteries are the Way to Go

Lithium-ion batteries are a promising alternative to the nickel metal hydride batteries used in current-generation HEVs. Lithium-ion NiMH batteries pack more power and energy into a smaller battery package. The volume and weight savings (about 60%) over a NiMH battery means less weight and more room for comfort in the vehicle. But there's work to do before lithium-ion batteries are ready for commercialization in this market.

Under the Department of Energy's Advanced Technology Development (ATD) Program, Argonne has been working with battery developers to overcome lithium-ion battery limitations and increase battery performance, life, and tolerance to abusive conditions (such as overcharge), while reducing cost. Argonne's work under this program provides a rich background for studying the particular requirements of batteries for plug-ins.

Similar technical challenges apply, but because PHEVs would utilize the all-electric mode more extensively than HEVs, there would be different demands on the batteries. For example, today's HEV batteries are used intermittently and typically discharge less than 5% before recharging. The PHEV duty cycle would include daily deep discharges of up to 75%, and battery life likely would be affected.

Argonne is focusing on developing advanced lithium-ion battery materials and cell chemistries that can meet the demands of PHEV use, and on simulating how batteries made with these new chemistries would perform under conditions typical for a PHEV.



At Argonne's Advanced Photon Source (APS), researchers load a lithium-ion battery pouch into an insertion device x-ray beamline in order to evaluate the electrode material structure stability during charging and discharging. The APS and Electron Microscopy Center are valuable research tools for Argonne's battery R&D. Shown here are Christopher Johnson (foreground) and Jeremy Kropf (background).

Argonne's Approach

Argonne will study prototype lithium-ion batteries of the type being used in the DaimlerChrysler Sprinter van program, which is targeted at demonstrating a PHEV van for use in fleet applications. Argonne will use two of the batteries in hardware-in-the-loop testing as part of breadboard vehicle systems. Another battery will be tested in Argonne's Electrochemical Analysis and Diagnostics Laboratory to characterize its performance and cycle life, as well as establish its capabilities and limitations for use in PHEVs.

Experts agree that a battery's ability to store and deliver energy at low cost is key to making PHEV technology viable. Argonne has discovered high-capacity cathode materials that exhibit capacity densities of ~270 mAh/g compared with the 150 mAh/g capacity density for state-of-the-art cathode materials. These materials are excellent candidates for lithium-ion batteries to power PHEVs, and research efforts are focused on increasing the rate capability and particle density of these materials, as well as making them more stable for longer battery life and enhanced safety, while reducing battery size.

Argonne's lithium-ion battery research is funded by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, FreedomCAR and Vehicle Technologies Program.

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Electric Power Research Institute and Argonne Agree to Collaboratively Assess Commercial Viability of Plug-In Hybrid Electric Vehicles

The Electric Power Research Institute (EPRI) and Argonne National Laboratory, two of the nation's premier research organizations, have entered into a three-year collaborative agreement to conduct the next level of analysis of plug-in hybrid electric vehicles (PHEVs) aimed at assessing the commercial feasibility of this technology.

EPRI and Argonne will analyze PHEVs versus hybrids and conventional vehicles, assessing them from environmental, cost, design, and marketing perspectives. The engineering and technical studies will be conducted at the two organizations' respective research facilities in Palo Alto, California, and Argonne, Illinois, and will involve the participation of some of the world's leading experts in vehicle transportation.

The objective of the multi-year research project is to provide a balanced and authoritative study of both the advantages of and the challenges to the design and commercial production of PHEVs. An assessment of potential social benefits of PHEVs, including reductions in imported petroleum-based fuels, enhancement of America's energy security, and air quality improvement will be key components of the study.

The research project, which is funded by the U.S. Department of Energy's FreedomCAR and Vehicle Technologies Program, is the latest in ongoing formative research that began in 2001 with the EPRI study, "Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options," and the Argonne study "Hybrid Electric Vehicle Technology Assessment." The new project will look carefully at the effect of PHEVs on the nation's economy, and their viability from an industrial and manufacturing perspective.

EPRI was established in 1973 as an independent, nonprofit center for public interest energy and environmental research. EPRI brings together members, participants, the Institute's scientists and engineers, and other leading experts to work collaboratively on solutions to the challenges of electric power. These solutions span nearly every area of electricity generation, delivery, and use, including health, safety, and environment. EPRI's members represent over 90% of the electricity generated in the United States. International participation represents nearly 15% of EPRI's total research, development, and demonstration program.

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New Version of PSAT Released

The developers of Argonne's award-winning Powertrain System Analysis Toolkit (PSAT) have announced that a new version of PSAT is now available for licensing and downloading. PSAT is the U.S. Department of Energy's (DOE's) FreedomCAR and Fuel Partnership Program's primary vehicle simulation tool. To date, more than 300 researchers worldwide at over 60 companies and universities have used PSAT for vehicle systems analysis, control strategy development, hardware-in-the-loop, and technology validation. PSAT is a forward-looking model that has been continually updated and enhanced, not only to meet the needs of DOE and Argonne, but also to incorporate changes suggested by current industry and university users.

PSAT V6.1, which runs with Matlab R14 (SP3 preferred), incorporates many features and improvements, including:

- New opening screen to differentiate light- and heavy-duty vehicle simulations
- Generation of HTML report for simulations and test data (requires Matlab Report Generator Toolbox)
- Hydraulic hybrid powertrain configuration
- StateFlow vehicle level control strategies, including those for acceleration, deceleration, and shifting (requires StateFlow Toolbox)
- Data analysis tab redesigned to allow easy comparisons of simulations or test data
- Ability to import test data into PSAT/Matlab environment for analysis and/or comparison with simulations
- Enhanced component models
- Additional component data
- Validated 2004 Prius vehicle model data based on Argonne's Advanced Powertrain Research Facility testing

In 2004, PSAT received an R&D 100 Award as one of the 100 best newly available products and technologies for commercial use from around the world. Also, the model is currently being used by 17 collegiate engineering teams to select their powertrains and develop control strategies as part of the multi-year Challenge X competition, a student engineering vehicle competition sponsored by DOE and General Motors.

What makes PSAT so popular? According to Randy Yost, Engineering Specialist in Analytical Tool Development at General Motors Corporation, "OEMs have limited resources and research funds for new technologies. We have to pick and choose very carefully where we put our money and in what technology. In PSAT, DOE and Argonne have developed a tool that helps speed up the process and allows us to look at many different technologies much sooner than we would otherwise. We need a model that's intuitive, easy to use and provides accurate results. PSAT gives us that."

More information is available on the PSAT web site at www.transportation.anl.gov/software/PSAT/index.html.

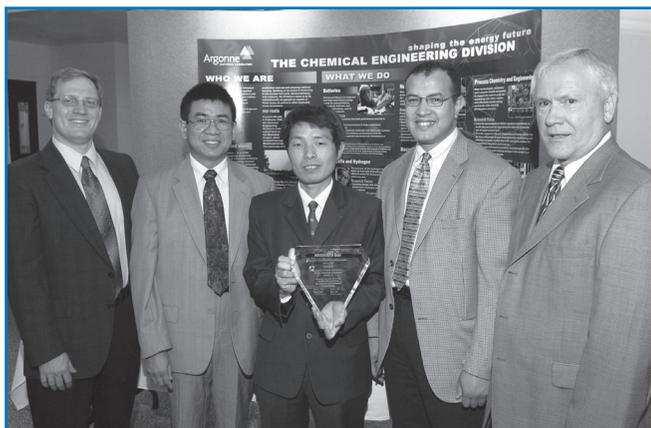
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Michael Wang's life-cycle analysis research was mentioned in a Newsweek Issues 2007 column by U.S. Energy Secretary Samuel Bodman entitled, "This Needs to Change." The column can be viewed at <http://www.msnbc.msn.com/id/16288772/site/newsweek/>.

Steve Ciatti received a Speaker Award from the Internal Combustion Engine Division of the American Society of Mechanical Engineers (ASME) for his paper, "Influence of EGR on Soot/NO_x Production in a Light Duty Diesel Engine," presented at ASME's 2006 fall technical conference in Ottawa, Canada. ASME is a 120,000-member professional organization focused on technical, educational, and research issues of the engineering and technology community.

J.G. Sun was awarded a patent for his optical technology for three-dimensional imaging of ceramic materials: J.G. Sun, Device and Nondestructive Method to Determine Subsurface Micro-Structure in Dense Materials, U.S. Patent No. 7,042,556, issued May 9, 2006.

Jin Wang received a speaker award from the Internal Combustion Engine Division of ASME for his paper, "Ultrafast Metrology of Fuel Injection: Microsecond X-Ray Phase-Contrast Micro-Imaging," presented at ASME's 2006 Spring Technical Conference in Aachen, Germany.



Shown here (left to right) are Argonne research team members Andrew Jansen, Jun Liu, Zonghai Chen, Khalil Amine, and Battery Technology R&D Department head Gary Henriksen.

in evaluating Air Products' new electrolyte salts, citing the group's understanding of the technology and needs of the lithium-ion battery industry, as well as the direction the industry is taking toward hybrid vehicles. Members of the Argonne team included Andrew Jansen, Jun Liu, Zonghai Chen, Khalil Amine, and Gary Henrikson, all of the Laboratory's Chemical Engineering Division.

The company turned to Argonne, with its nearly four decades of experience in lithium battery research and development, for help in determining the salts' viability for use in lithium-ion batteries. Argonne confirmed that the salts work in lithium batteries, and demonstrated that they remain non-corrosive if they become contaminated with moisture. Moreover, Argonne identified several key additives and solvents that enable the company's new salts to be used with common lithium-ion electrodes, forming a promising new electrolyte for the lithium battery industry.

Argonne's Work-For-Others agreements are a convenient and effective way for industry to enhance its knowledge and capabilities and find answers to the most challenging questions about its technology. Contracts are tailored to meet the specific needs of the sponsor, built on Argonne's background research, and information is maintained in confidence.

"Argonne scientists work best at coupling basic science to applied technology," said Steve Ban, director of Argonne's Office of Technology Transfer. "Certainly the development of new electrolyte systems for advanced lithium batteries fits that situation well and addresses a high priority need in energy — both are key elements of the Argonne mission."

Industrial Research Partner Honors Argonne for Exceptional Collaboration

Air Products and Chemicals of Allentown, Pennsylvania, has given Argonne its 4th annual External Collaboration Award.

The company created the award to recognize the results of external-partner collaborative research to demonstrate its commitment to building relationships and strengthening collaborations with external partners, and to stimulate the development of intellectual property with them.

The award recognizes the Battery Technology Department of Argonne's Chemical Engineering Division for its work

PUTTING ARGONNE'S RESOURCES TO WORK FOR YOU

Industrial technology development is an important way for the national laboratories to transfer the benefits of publicly funded research to industry to help strengthen the nation's technology base. The stories highlighted in this issue of *TransForum* represent some of the ways Argonne works with the transportation industry to improve processes, create products and markets, and lead the way to cost-effective transportation solutions, which in turn lead to a healthier economic future.

By working with Argonne through various types of cost-sharing arrangements, companies can jump-start their efforts to develop the next generation of transportation technologies without shouldering the often prohibitive cost of initial R&D alone. Argonne has participated in dozens of these partnerships and has even been involved in helping to launch start-up companies based on the products and technologies developed here.

If working with world-class scientists and engineers, having access to state-of-the-art user facilities and resources, and leveraging your company's own capabilities sound like good business opportunities to you, please contact our Office of Technology Transfer and see how we can put our resources to work for you.

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