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News From Argonne's Transportation Technology R&D Center

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Page 2

VIEWPOINT

Narrowing the Field: Key Transportation Players Participate in Study to Help Focus Automotive Research

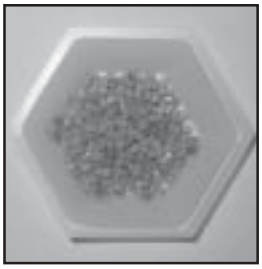
A new study sponsored by General Motors Corporation and supported by Argonne, BP, ExxonMobil, and Shell may bring us one step closer to focusing the public debate about which are the cleanest and most efficient fuels and propulsion systems for the next generation of vehicles. The study, titled *Well-to-Wheel Energy Use and Greenhouse Gas Emissions Analysis of Alternative Fuel/Vehicle Systems*, examines the energy efficiency and greenhouse gas emissions associated with gasoline and diesel internal combustion engines and fuel-cell and hybrid vehicles powered by a variety of fuels. *Page 2*

Page 5

RESEARCH REVIEW

Ethanol Fuel Additive May Help Solve the Diesel Emissions Puzzle

The quest to reduce atmospheric emissions associated with diesel-fueled vehicles has faced a longstanding "Catch-22" conundrum: lower particulate matter (PM) emissions, and the emissions of nitrogen oxides (NO_x) increase; push down the NO_x levels, and PM emissions rise. The ongoing diesel engine research program at Argonne has uncovered a promising approach to solving this problem. Within certain operating ranges, it turns out, using an ethanol fuel additive reduces both PM and NO_x emissions. *Page 5*



Page 6

Catalyst for Change: Licensing of Argonne's Patented Catalyst Technology Brightens Prospects for Fuel-Cell-Powered Cars

Last fall, Sud-Chemie, Inc., a Louisville, Kentucky-based company, signed a licensing agreement to manufacture and distribute a partial oxidation catalyst developed by Argonne to efficiently convert a wide variety of hydrocarbon fuels — including gasoline, natural gas, diesel, and methanol — into hydrogen-rich gas to power automotive fuel-cell systems. The company has already shipped prototypes to virtually every fuel-processor developer in the automotive and stationary applications industries. *Page 6*

LOOKING DOWN THE ROAD *Page 7*

FASTRAX *Page 7*

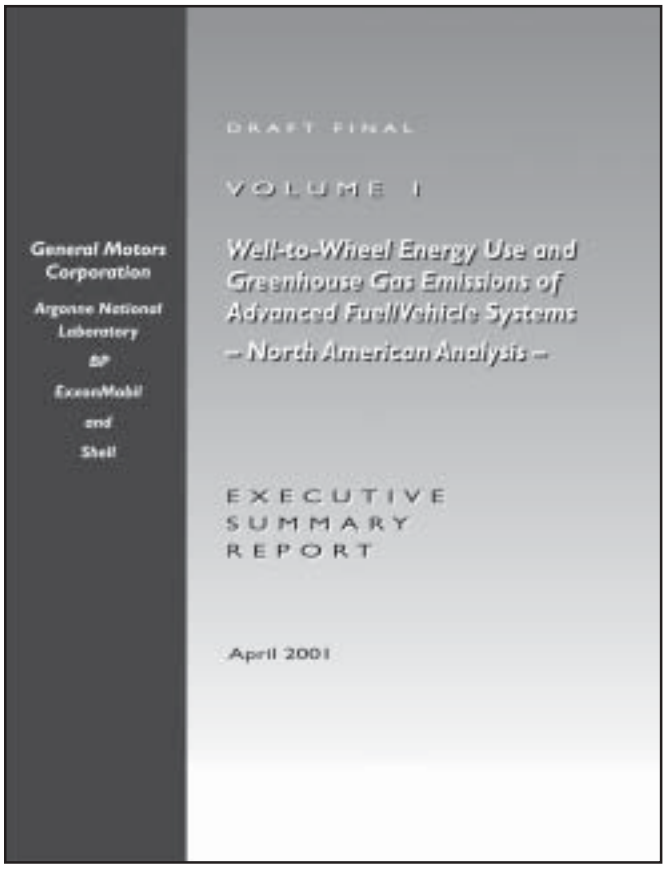
PARTNERING WITH ARGONNE *Page 8*

Narrowing the Field

Key transportation players participate in study to help focus automotive research

The debate has rumbled on for years: which are the most promising vehicles and fuels for the long term? A new study sponsored by General Motors Corporation (GM) and supported by Argonne, BP, ExxonMobil, and Shell may bring us one step closer to finding the answer. On March 21, 2001, at a conference in New Orleans, GM announced the publication of a new study that the automaker hopes will help focus the public debate about which are the cleanest and most efficient fuels and propulsion systems for the next generation of vehicles. The study found that hydrogen-powered fuel-cell vehicles represent the best long-term solution in terms of combined energy use and greenhouse gas emissions; other fuels can be used to pave the way for hydrogen fuel-cell vehicles (see sidebar, page 3).

The study, titled *Well-to-Wheel Energy Use and Greenhouse Gas Emissions Analysis of Alternative Fuel/Vehicle Systems*, employed a common platform — the Chevrolet Silverado pickup — to examine the energy efficiency and greenhouse gas emissions associated with gasoline and diesel internal combustion engines and fuel-cell and hybrid vehicles powered by a variety of fuels. To increase the breadth and credibility of the study, GM recruited researchers at Argonne National Laboratory and representatives of the three largest privately owned energy companies (BP, ExxonMobil, and Shell).



TransForum sat down with some of the key players to learn their thoughts about the study's significance and its impact on future automotive and fuels research. Excerpts from the interviews are provided below. The report is available on Argonne's Transportation Technologies Research and Development Center (TTRDC) web site (www.transportation.anl.gov).

TF: What is the significance of this study? How does it differ from other studies that compare various vehicle fuels and technologies?

Greg Ruselowski (GM): What we did was try to take a very holistic approach. We looked at 75 different fuel pathways and 15 different vehicle propulsion systems, so the scope is much broader than anything that we've seen done before. Also, we chose one very high-volume product and benchmarked all of our propulsion systems against that. In some of the other studies, it's not clear that they were truly apples-to-apples comparisons.

The other thing that makes our report unique is that we not only involved Argonne to help lead the effort, but also got three of the world's largest energy companies involved. And it really worked out quite well — much better than we thought. I think at the end of the day, everyone has been extremely satisfied with the results.

Jim Simnick (BP): There are a couple things that are significant. The first is that we had great cooperation among energy companies, an automotive company, and a national lab to try to put together a study that was objective, broad in scope, and that will have an impact. It's not one particular interest looking at their favorite fuel but rather an objective look at a whole slew of different fuels and fuel/vehicle combinations. Another significant feature of this study was that, rather than looking at the individual efficiencies of making gasoline or methanol or hydrogen, or even taking a car with a fuel-cell power plant or a hybrid power plant, we also reflected the uncertainty in the estimates.

Michael Wang (ANL): The study provides critical technical input to the current debate regarding fuel choices for fuel-cell vehicles. The participation by the energy companies forced the study team to examine their key assumptions much more thoroughly.

TF: How do you hope that this study will influence public and private decision makers regarding the introduction of advanced fuel/vehicle propulsion systems?

Greg Ruselowski (GM): The study can help influence public policy in terms of where we should focus our efforts — what types of fuels and technologies make the most sense. I think it will help the auto and energy companies as well in developing business strategies to optimize the fuel choices and propulsion systems that really make the best long-term sense, not only for our companies but for society in general.

Gilbert Jersey (ExxonMobil): ExxonMobil is very oriented toward an approach of sound science for making sound decisions, so this study is really one opportunity for bringing outstanding science that has been developed in this area to the forefront to make it part of the technical dialogue.

Jean Cadu (Shell): I think that responsible people cannot ignore the conclusions of the study. I hope that it will help put some sort of flexibility into emissions legislation for passenger cars because some of the fuel/vehicle systems will have trade-offs among the different pollutants. In Europe, there are two sets of emissions standards, one for diesel and one for gasoline, which makes sense. In the USA, there is only one series of limits, and diesel is completely left out.

TF: How (and why) did GM decide to involve the energy companies and Argonne in its analysis?

Greg Ruselowski (GM): There are a lot of these studies out there. We wanted this to be the gold standard that everybody could look at. We felt that getting ANL involved was absolutely critical because of the level of credibility that the Laboratory brings in terms of being impartial. Also, Michael Wang's GREET model has been recognized around the world. When we looked at a number of other organizations to perhaps participate in the effort, most of them were using Michael's model, so we figured, let's just go to the source. Getting the energy companies involved was also critical in terms of helping to put in the right assumptions and to add credibility to this study so that when it did come out, it would be perceived — rightly so — as the standard by which to measure future work.

TF: Did the results of the study surprise anyone, or did they confirm that the areas in which your companies had already been focusing their research were the right ones?

Greg Ruselowski (GM): Actually, the results were not unexpected. We all recognize that fuel cells are the ultimate solution, but there were a lot of questions about what fuel makes the most sense. I think one of the surprising things was how well diesel fared. It's a very efficient fuel for the vehicle, but it also turns out to be a very efficient fuel to make. The other thing that I'd like to focus on is the methanol versus gasoline debate for the fuel cell. We worked with methanol for many years and we knew it had an advantage on the vehicle side, but on the well-to-tank side, we knew that there was a disadvantage. The results confirmed what we had thought, but by laying it out in a very consistent manner, we made our conclusions readily apparent to anybody looking at it; there were a lot of different studies showing conflicting data.

Study Results

Considering both total energy use and GHG emissions, the key findings of the study are as follows:

- **Among all of the crude oil- and natural gas (NG)-based pathways studied, the diesel compression ignition direct injection (CIDI) hybrid electric vehicle (HEV), gasoline and naphtha fuel-cell HEVs and the gaseous hydrogen (GH_2) fuel-cell HEVs were the best — and nearly identical — in terms of total system energy use (Btu/mi). Among these pathways, however, expected GHG emissions were lowest for the GH_2 fuel-cell HEV and highest for the diesel CIDI HEV.**
- **Compared with the gasoline conventional vehicle, the gasoline and diesel CIDI HEVs, as well as the diesel CIDI (conventional) vehicle, yield significant total system energy use and GHG emission benefits.**
- **The methanol fuel-cell HEV offers no significant advantages over the crude oil-based or other NG-based fuel-cell HEV pathways when both energy use and GHG emissions are considered.**
- **Ethanol-based fuel/vehicle pathways have by far the lowest GHG emissions of the pathways studied and also do well on well-to-tank energy use when fossil fuel consumption is the focus.**
- **On a total system basis, the energy use and GHG emissions of CNG conventional and gasoline conventional pathways are nearly identical.**
- **The crude oil-based diesel vehicle pathways offer slightly lower total system GHG emissions and considerably better total system energy use than the NG-based Fischer-Tropsch diesel CIDI vehicle pathways. (Note that criteria pollutants are not considered.)**
- **Liquid hydrogen, Fischer-Tropsch naphtha, and electrolysis-based H_2 fuel-cell HEVs have significantly higher total system energy use and the same or higher levels of GHG emissions than the gasoline and crude naphtha fuel-cell HEVs and the GH_2 fuel-cell HEVs.**

Gilbert Jersey (ExxonMobil): I think we learned a few things that we didn't know before as a result of interacting with the various groups, particularly with General Motors. It was an opportunity for us to really understand the nuances of the vehicle technology.

Jean Cadu (Shell): I think what came as a great surprise was the ethanol pathway, especially on a CO_2 basis. The success of the diesel hybrid was also a surprise. It verified the things we had already worked out, but this study is a real confirmation that diesel hybrids are a feasible option.

TF: What is planned for the next phase of the study?

Greg Ruselowski (GM): The next phase will focus on criteria pollutants and developing a European counterpart to the current study. Nobody has done any really good work on criteria pollutants. This one's going to be a real challenge. So we're looking forward to working with Argonne and the energy companies on that.

Also, there are some issues specific to Europe in terms of some of the fuel pathways, which are a little different. The vehicles are smaller. We're not sure that we're going to see huge differences. But there are enough differences in the way people drive, where they get the fuel; the powertrains are a little smaller, a little more efficient than what's available here, and so it's worth doing.

Jean Cadu (Shell): Shell will be involved in both parts of the study. Estimating criteria pollutants along the various fuel chains will be more complex, but the challenge is worth it. Shell looks forward to contributing to the European counterpart of this study, also led by GM.

Jim Simnick (BP): We will be involved in both parts of the study; it should be interesting because this is uncharted territory. We look forward to working with this group again, and we believe the second part of the study will be as good as the first.

The study team (seated): Dan Santini, Argonne; Tony Finizza, AJF Consultants; Jim Wallace, Wallace and Associates; Jean Cadu, Shell; and Marianne Mintz, Argonne. (Standing): Norm Brinkman, GM; Michael Wang, Argonne; Greg Ruselowski, GM; Gilbert Jersey, ExxonMobil; Mike Kerby, ExxonMobil; Jim Simnick, BP; and Chris Saricks, Argonne.

Ethanol Fuel Additive May Help Solve the Diesel Emissions Puzzle

The quest to reduce atmospheric emissions associated with diesel-fueled vehicles has faced a longstanding "Catch-22" conundrum: lower particulate matter (PM) emissions, and the emissions of nitrogen oxides (NO_x) increase; push down the NO_x levels, and PM emissions rise. Both PM and NO_x are major contributing factors to smog (ozone) and other air pollution problems.

Not long ago (see *TransForum*, Volume 1, Number 4), researchers at Argonne found a high-tech way to resolve this paradox — their solution involved a revolutionary new membrane technology and closely controlled operating conditions. The discovery, hailed by former U.S. Department of Energy (DOE) Secretary Bill Richardson as a major step in addressing air pollution associated with diesel engines, was originally tested on a locomotive engine. The ongoing diesel engine research program at Argonne has uncovered another promising approach to solving the diesel conundrum.

Within certain operating ranges, it turns out, using an ethanol fuel additive reduces both PM and NO_x emissions. "We expected to see a decrease in particulate matter," says Roger L. Cole, a researcher at Argonne's Center for Transportation Research. "What was unexpected was the large decrease in NO_x."

According to Cole, "Our tests of this fuel-additive alternative covered almost all of the U.S. Environmental Protection Agency's (EPA's) two test cycles: the FTP (city and suburban) and the US 06 (faster accelerations, higher speeds). The range in which both PM and NO_x were reduced represents a fraction of our test area; we are confident that, with more research, we can achieve a broader range."

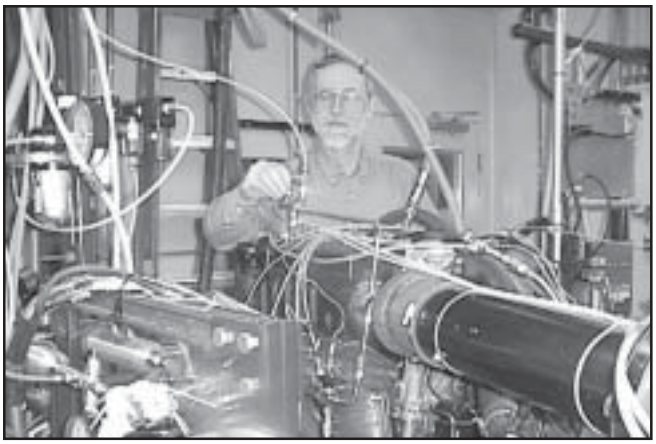
Using special facilities at AutoResearch Laboratories (Chicago, Illinois), Cole and his colleagues tested the enhanced fuel, E-Diesel — a proprietary formulation of diesel, ethanol, and a solubilizing agent (called Puranol) developed by Pure Energy Corporation of New York — on a 1.9-L Volkswagen diesel engine. With the addition of 15% ethanol, PM emissions were reduced by up to 75% and NO_x emissions by up to 84%. These very striking results were obtained in an operating region corresponding to loads greater than 105 N·m (50% load) and engine speeds less than 1,700 rpm. This region (high loads at low speeds) is of greatest interest for heavy-duty engines, but the research can also be applied to automobile diesel engines.

The engine used in the Argonne testing was equipped for exhaust-gas recirculation (EGR), which can affect emissions levels; similar tests with modified EGR rates, modified fuel injection timing, and modified turbocharger boost are needed to broaden the range of these results.

Heavy-duty trucks and buses today account for about one-third of NO_x emissions and one-quarter of PM emissions from mobile sources. In some urban areas, the contribution is even greater. With more stringent heavy-duty diesel engine standards set to take effect in 2002, and extremely low emissions levels targeted for 2007, Argonne's findings about the effects of the ethanol additive on diesel fuel emissions point the way for industry to meet the upcoming EPA emission standards, which allow for use of alternative fuels. "Eliminating the visible smoke and the harmful emissions associated with diesel engines," Cole suggests, "will go a long way toward making diesel trucks, and perhaps even diesel cars, more acceptable."

The use of ethanol-enhanced diesel fuel in vehicles, trucks, buses, trains, shipping, power generation, and other major petroleum markets could also lead to significant energy savings. In addition, the successful blending of ethanol and diesel fuel could stimulate both the ethanol industry in Illinois (with an annual production of more than 600 million gallons, the leading producer of ethanol in the United States) and the agricultural economy across the nation. Says Cole, "This research will provide another approach to breaking the barrier of NO_x and particulate trade-offs."

The work was sponsored by the Illinois Department of Commerce and Consumer Affairs and DOE's Office of Advanced Automotive Technology.



Testing of a 1.9-L Volkswagen diesel engine by Argonne researchers revealed that particulate and NO_x emissions can be significantly reduced by using a diesel-ethanol blend.

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Catalyst for Change

Licensing of Argonne's patented catalyst technology brightens prospects for fuel-cell-powered cars

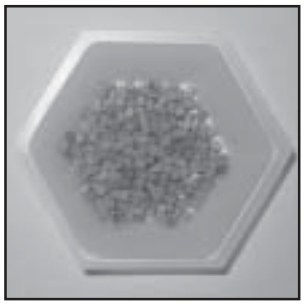
Reactions were largely negative when Argonne's Chemical Technology Division began exploring the catalytic conversion of liquid fuel to hydrogen inside a fuel-cell system. Late 1980s conventional wisdom held that the sheer difficulty of finding the right catalyst made such work too risky.

Over the next decade, diligent work by an Argonne team, led by Michael Krumpelt and Shabbir Ahmed, would uncover a class of new materials to support the chemistry for partial oxidation — the primary reaction by which the hydrocarbon fuel is converted into hydrogen *(TransForum*, Volume 2, No. 1*)*. That discovery would lead to the development of a partial oxidation catalyst that efficiently converts a wide variety of hydrocarbon fuels — including gasoline, natural gas, diesel, and methanol — into hydrogen-rich gas to power automotive fuel-cell systems.

The bottom line is that the novel catalyst — contained within a fuel processor that is only about two gallons in size — will allow fuel-cell-powered cars to run on conventional fuels. Such a breakthrough means the era is approaching when ultra-efficient, environmentally benign electric cars can compete with the internal combustion engine for consumers' affections.

As might be expected, interest in Argonne's patented catalyst has grown. Last fall, Sud-Chemie, Inc., a Louisville, Kentucky-based supplier of catalysts used in fuel-cell processors, signed a licensing agreement to manufacture and distribute the partial oxidation catalyst. The company has already shipped prototypes to virtually every fuel-processor developer in the automotive and stationary applications industries.

"Clearly, the partial oxidation catalyst is a leading-edge technology," says Scott Osborne, business development manager for Sud-Chemie's fuel-cell catalyst technology division. "Its greatest attribute is its ability to process gasoline and heavy feeds, which eliminates the need to produce straight hydrogen fuel for fuel-cell applications. In addition, the catalyst offers impressively high tolerance for sulfur in hydrocarbon fuels, and it eliminates or reduces coke formation. Such successful performance is critical to the reliable, long-term operation of the processor."



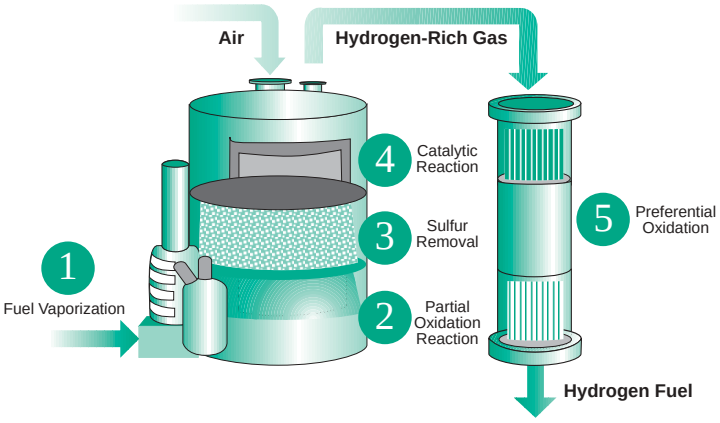
Catalyst pellets made by Sud-Chemie.

Krumpelt agrees. "The fuel cell itself had progressed far enough to build vehicles, but what was missing was the technology to convert gasoline to hydrogen-rich gas for the fuel cell. The partial oxidation catalyst has provided that missing link. Others have developed catalysts to compete, but this is the first and by far the best application."

More work on the partial oxidation catalyst is needed. Although industry response to the catalyst has been favorable, current interest appears to be limited largely to demonstration programs and additional research. That could change, but large-scale production is still at least several years away.

At Argonne, the work has now entered what Krumpelt calls the "clever engineering" phase. The emphasis will be on sharply reducing the cost of the fuel processor by making it smaller, lighter, and more efficient. Key tasks will include trimming the size and weight of the catalyst by half and boosting efficiency by improving thermal integration. All are difficult, but not insurmountable, challenges.

Meanwhile, the agreement with Sud-Chemie is expected to spawn new cooperative research, which could lead to the development of a whole new generation of fuel-processor catalysts. The work conducted thus far was sponsored by DOE's Office of Transportation Technologies.



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LOOKING DOWN THE ROAD

I am an avid bike rider. When I ride into work in the morning, I can't help feeling a little smug as I pass by the gas stations where motorists are waiting in line to hand over $2 a gallon to fill their tanks. So where do we go from here? Where do we focus our dollars and research efforts? Hybrids, alternative fuels, fuel cells? The study described in this issue's Viewpoint (page 2) provides new insights into the question, "Which alternatives make the most sense for the long term?"

It was an ambitious idea — bring together top experts from an auto manufacturer, three of the largest energy companies, and a national laboratory known for its expertise in transportation issues to conduct a careful, methodical study of energy use and emissions of 75 fuel pathways across the entire fuel cycle (well-to-wheels). In many ways, the results of the study are not surprising — fuel cells offer the best long-term solution and other fuels, used in hybrids, can be used to bridge the gap until fuel-cell vehicles are ready for commercialization. What is surprising is that three very different interests with three very different agendas can come to some consensus about the meaning of the results. Like PNGV before it, this partnership offers a glimpse into what can be accomplished by pooling our respective resources to conduct good science. The study is posted on our web site (www.transportation.anl.gov) and makes for some very interesting reading.

The Research Reviews included in this issue also underscore the advantages of our research partnerships. In his interview, Greg Ruselowski of GM said of diesel that, "One of the surprising things was how well diesel fared. It's a very efficient fuel for the vehicle, but it also turns out to be a very efficient fuel to make." We have worked with numerous industrial partners in our ongoing diesel engine research program at Argonne, which has recently uncovered another promising approach (page 5) to making diesel environmentally acceptable.

The recent licensing of Argonne's partial oxidation catalyst by Sud-Chemie brings us one step closer to a day when ultra-efficient, environmentally benign fuel-cell cars can compete with the internal combustion engine.

Larry R. Johnson
Director
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FASTRAX

Michael Wang has been asked by the San Francisco-based Energy Foundation to serve on its board of directors. The Energy Foundation was created in 1991 by the Rockefeller Foundation, the John D. and Catherine T. MacArthur Foundation, and the Pew Charitable Trusts to provide grants to non-profit organizations and universities to promote energy efficiency in all economic sectors. The 12-member board of directors provides input to the foundation regarding its grant directions. The Foundation has established a program in China with seven staff members stationed in Beijing to promote energy-efficient and clean technologies, primarily in China's utility and transportation sectors.

Edward Daniels, Bassam Jody, and **Joseph Libera** (formerly of Argonne) developed an efficient, economical process to separate flexible polyurethane foam (FPUF) from automobile-shredder residue and clean it to produce high-quality reusable foam. Their discovery is one of four Argonne accomplishments that have been named among the **"100 Best Scientific and Technological Accomplishments"** of the Department of Energy during the 20th Century. DOE developed the list to "demonstrate [its] commitment to save consumers money and improve [their] quality of life."

Frank Stodolsky, Linda Gaines, Christopher Marshall, Feng An, and **James Eberhardt** received the Society of Automotive Engineers's (SAE's) Arch T. Colwell Merit Award recognizing the authors of papers of outstanding professional and technical merit. Papers are judged primarily for their value as new contributions to existing knowledge about mobility engineering. The winning paper was titled *Total Fuel-Cycle Impacts of Advanced Vehicles*. Frank Stodolosky also received the Forest R. McFarland Award recognizing his outstanding voluntary contributions as an SAE technical paper reviewer (2000 Future Car Congress), session organizer (Advanced Hybrid Vehicle Powertrain and Electric Vehicle sessions), and Chair for the Advanced Powerplant Committee.

Five communications products prepared for Argonne's TTRDC sponsors (including one *TransForum* article) received "Excellence" or "Merit" awards in the publication and art categories of the 28th Annual Chicago Technical Publications, Art, and On-Line Communications Competition. These awards indicate that "the judges found that the products consistently met high standards in all areas and demonstrated an exceptional understanding of technical communications principles."

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 startup 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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