

Trans Forum™

News From Argonne's Transportation Technology R&D Center

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■ VIEWPOINT

Argonne Poised to Meet FreedomCAR Needs

Some say that luck is 90% preparation. If so, Argonne is in a fortunate position to help the U.S. Department of Energy and USCAR (DaimlerChrysler, Ford, and General Motors) meet the needs of FreedomCAR, a new government-industry research program aimed at reducing America's dependence on petroleum through the development of hydrogen-powered fuel-cell cars and light trucks.



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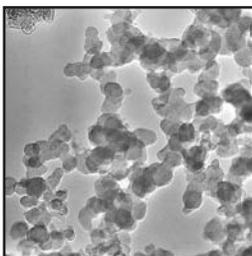
■ RESEARCH REVIEW

Viewing Our Economic Future

For most of last year, government officials, economists, and the rest of us wondered, "Is a full-blown recession lurking in the not-so-distant future?" The million-dollar question had many economists pondering probable scenarios. Among them was Dan Santini of Argonne's Center for Transportation Research. This economic wizard didn't need a crystal ball to foresee the future. Instead, he relied on two simple, but practical models he developed to predict oil price shocks and subsequent recessions. An important emphasis of Santini's theory is the effect of the transportation sector on the economy. *Page 4*

Nanofluids Could Help Open Door to Advanced Truck Designs

Truck manufacturers are constantly seeking ways to improve the aerodynamic designs — and thus increase the fuel economy — of their vehicles. The large radiators needed to cool the truck engines contribute to aerodynamic drag. If the fluids used in these radiators had higher heat capacities and could absorb and release heat very quickly, the radiators could be made smaller and configured to allow for more streamlined designs. Argonne researchers are developing a new class of heat-transfer fluids, called nanofluids, that provide engine coolants with the high thermal conductivities they need. *Page 5*



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Zeroing in on Diesel Particulate Emissions

Scientists need to study ways of further improving diesel performance because the small soot particles generated by today's diesel engines may pose greater health concerns than the large particles emitted from older engines. Researchers at Argonne have mounted a major effort to understand how engine speed and load conditions influence the particle formation process — which will help them develop effective ways of significantly reducing diesel particulate emissions. *Page 6*

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Argonne Poised to Meet FreedomCAR Needs

Some say that luck is 90% preparation. If so, Argonne's experience has put the laboratory in a fortunate position to help the U.S. Department of Energy (DOE) and USCAR (DaimlerChrysler, Ford, and General Motors) meet the needs of FreedomCAR, a new government-industry research program announced by Secretary of Energy Spencer Abraham on January 9. FreedomCAR is aimed at reducing America's dependence on petroleum through the development of hydrogen-powered fuel-cell cars and light trucks. FreedomCAR focuses on the basic research needed to provide a full range of fuel-cell vehicles that use no petroleum and produce no harmful emissions. Fuel cells combine hydrogen fuel with oxygen from the air to create electricity, which powers vehicles by means of electric motors. Hydrogen offers a promising energy alternative to fossil fuels because it can be made from water or renewable resources and produces only water when used to generate power.

Fuel-cell research is not new. In fact, Argonne has been a leader in the field for more than 20 years. During that time, the Laboratory, sponsored by DOE, has fostered a long line of innovations in new materials, analytical methods, and design concepts for advanced fuel-cell systems. Our experience and capabilities could prove vital to the new FreedomCAR program. Some of our current fuel-cell research is highlighted below, with links to web pages that provide more information about each topic.

Hydrogen Production

There would be little advantage to developing nonpolluting fuel-cell vehicles if the systems used to manufacture hydrogen fuel generated and released significant amounts of polluting gases. Current hydrogen production technologies (widely used in petroleum fuel refining and fertilizer manufacture) do just that, because hydrogen production consumes a lot of energy, which typically comes from burning fossil fuels. One goal of the FreedomCAR program, therefore, is to help devise methods of creating vast quantities of hydrogen in sustainable and environmentally responsible ways.

Argonne researchers are working to develop an economical thermochemical process that uses the next generation of nuclear reactors to provide a pollution-free heat source for hydrogen manufacture. The system employs a modular fast-neutron reactor that can exploit the full energy content of uranium, thereby reducing concerns about nuclear proliferation. Working with Argonne on reactor development are researchers at Texas A&M University, General Electric, the Japan Atomic Energy Research Institute, and the Italian National Agency for New Technology, Energy and Environment.

<http://www.anl.gov/OPA/whatsnew/000721neristory.htm>

Reformer Catalyst

Because it will take a decade or more before a hydrogen production, storage, and delivery infrastructure is in place, carmakers are expected to adopt an interim fuel-cell technology based on gasoline, natural gas, or some other fuel that is readily available to consumers. Vehicles of this type would have an onboard fuel processor (fuel reformer) that would strip hydrogen from the fuel, allowing vehicles to make their own hydrogen on an as-needed basis.

With support from DOE's Office of Advanced Automotive Technologies, Argonne has developed a reforming catalyst that is the key component of a fuel reformer that can efficiently convert gasoline, diesel fuel, natural gas, methanol, or ethanol into a hydrogen-rich fuel. Because of the catalyst's potential importance in hastening the commercialization of fuel-cell vehicles, the technology won a coveted R&D 100 Award in 2001 and has recently been licensed by a catalyst supplier for fuel-cell processors.

<http://www.transportation.anl.gov/ttrdc/publications/transforum/v3n2/fuelcell-catalyst.html>



Michael Krumpelt, of Argonne's Chemical Technology Division, displays the new catalyst he and his colleagues developed to help bring fuel-cell vehicles to the marketplace. The catalyst was named one of the top 100 technological innovations by R&D Magazine in 2001.



Total Fuel-Cycle Analysis

Argonne's Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model was developed to assist decision makers in selecting the fuel that achieves the greatest overall benefits when used in advanced vehicles, including fuel-cell systems. The software model provides complete well-to-wheel evaluations of how energy and emissions considerations change when fuel-cell vehicles use different fuels.

<http://www.transportation.anl.gov/ttrdc/greet/index.html>

Hydrogen Infrastructure Analysis

Introducing new transportation technologies requires careful planning. Argonne has developed comprehensive analysis techniques to provide projections of the effects that advanced transportation technologies will have on society and the influence of government policies on their development and use. A current research project is examining accelerated hydrogen production scenarios. Argonne researchers are trying to find out how many hydrogen-fueled vehicles could be supported by 2010, 2015, and 2020.

<http://www-db.research.anl.gov/db1/ttrdc/document/DDD/128.pdf>

Computer Modeling

Although fuel-cell vehicles are mechanically simpler than vehicles that employ conventional internal combustion engines, they still consist of many interacting systems, which pose difficulties in optimizing vehicle designs. To aid in this process, Argonne developed the General Computational toolkit (GCTool), a versatile simulation software package for designing, analyzing, and comparing different power-plant configurations. Argonne's GCTool lets designers "try out" different system configurations without the expense and delays of actually building numerous prototypes. More than a dozen organizations outside of Argonne are using GCTool for systems analysis and evaluation.

<http://www.transportation.anl.gov/ttrdc/modeling/gctool-new.html>

Fuel-Cell Test Facility

The Fuel-Cell Test Facility at Argonne provides fuel-cell developers, government agencies, and U.S. automakers with independent testing to evaluate and validate fuel-cell stacks and systems up to 50 kW. The facility furnishes direct comparisons of alternative fuel-cell technologies in terms of

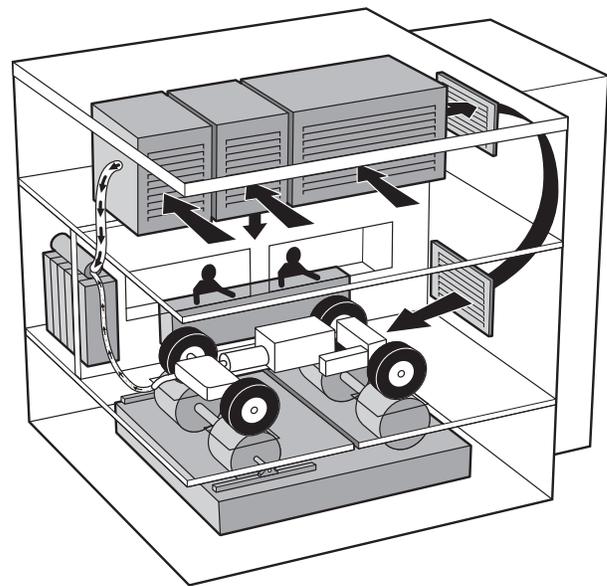
performance and operational characteristics. Argonne's independent testing clarifies claims and helps validate the capabilities of differing technologies.

<http://www.transportation.anl.gov/ttrdc/facilities/fuelcelltest.html>

Four-Wheel-Drive Chassis Dynamometer Test Cell

Argonne has lead responsibility for a program with DOE's Office of Transportation Technologies to conduct emissions and energy-efficiency tests on hybrid electric vehicles (HEVs), sport utility vehicles, and advanced-technology vehicles, including fuel-cell vehicles. The world-class facility being developed at Argonne is capable of benchmarking the most advanced powertrains for future cars and trucks. The test cell, which will be operational this summer, contains a state-of-the-art electric four-wheel-drive chassis dynamometer that will operate in a climate-controlled environment for highly accurate emissions and fuel measurements.

<http://www.transportation.anl.gov/ttrdc/facilities/ct6-4WD.html>



Argonne's new four-wheel-drive chassis dynamometer will be used to test fuel-cell and other advanced-technology vehicles.

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Viewing Our Economic Future

Will history repeat itself? Which recession is the "model" for understanding this one?

For most of last year, government officials, economists, and the rest of us wondered, "Is a full-blown recession lurking in the not-so-distant future?" The million-dollar question had many economists pondering probable scenarios. Among them was Dan Santini of Argonne's Center for Transportation Research. This economic wizard didn't need a crystal ball to foresee the future. Instead, he relied on two simple, but practical models he developed to predict oil price shocks and subsequent recessions. Santini used these models to predict, in a 1999 conference paper, the 2000-2001 oil price shock and subsequent recession.

Although many economists believe that the terrorism of September 11 tipped the economy into a recession, Santini asserts that the sharp decline in the rate of economic growth from 2000 to 2001 would, with or without September 11, have been comparable to or greater than those that preceded the recessions of 1970, 1980, or 1991.

An important emphasis of Santini's theory is the effect of the transportation sector (in its entirety) on the economy. According to his theory, after a fuel price increase, motor vehicle sales and output decline, pulling the other elements of the economy downward in rapid succession. In other words, recessions are caused primarily by significant difficulties in the transportation sector. Thus, while terrorism was not a factor in Santini's prediction, to the extent that declines in aircraft sales and air transportation are having a strong negative effect, what we have seen since September is consistent with his general arguments.

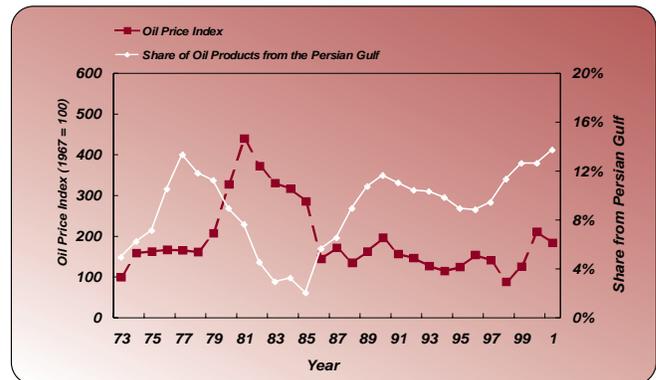
Santini's prediction of a recession after a fuel price shock is based on statistical investigations using data from the late 1800s to the present. "Over the full period examined, my historical statistical analyses showed that recessions tend to follow sharp fuel price increases by one year. These analyses suggested that if there was going to be a recession this time, it would be in 2001."

Santini has accurately predicted two other sharp fuel price shocks — in 1985 (a dramatic drop) and 1989. He also warned of the high risk of a recession in an 1989 paper — a recession that occurred in the second half of 1990 and first quarter of 1991.

In both the 1990 and 2001 cases, the oil and gasoline price shock triggered a sharp decline in motor vehicle output, which was followed by economic decline in the rest of the economy, and a recession. Santini points out that the declines in motor vehicle output in both cases preceded disastrous events in the Middle East. In 1990, Iraq invaded Kuwait, causing another upward push to oil prices that had previously risen significantly, but had begun to move down. In 2001, the terrorist attacks also occurred months after the motor

vehicle output decline had bottomed out and gasoline prices had begun to move down.

What about oil use and energy security today? "What is happening now is in some ways reminiscent of the mid 1970s, when the Arab oil embargo and oil price shock of 1973-74 caused a lengthy recession in 1974-75. A discouraging difference is that the United States is much more dependent on Middle Eastern oil than it was in 1973, and this dependence is rising. On the positive side, the reasonably rapid decreases in dependence after the more recent 1988-1990 oil price shock serve as a reminder to Middle Eastern producers that alternatives are available.



Rising shares of imports from the Persian Gulf preceded the oil price shocks of 1978-1981, 1988-1990, and 1998-2000.

Santini recommends that economists show more interest in fuel efficiency at times when fuel prices are low and supply seems abundant — an approach that has gained popularity recently. "Fuel prices are among the most volatile of all prices, and repeated fuel price shocks that slow or reverse economic growth have actually been typical of the U.S. economy for two centuries now." To create a more stable economy, he suggests that the United States begin adapting its behavior, as have such energy-poor industrialized nations as France, Japan, and Germany. Those nations combine higher fuel taxes and more fuel-efficient technologies. By following the example of these nations, the United States could help ensure that its economy is less susceptible to the effects of global instability and oil price shocks.

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Nanofluids Could Help Open Door to Advanced Truck Designs

Driven by the need for higher-horsepower engines and by new emissions-reduction technologies, truck manufacturers are constantly seeking ways to improve the aerodynamic designs — and thus increase the fuel economy — of their vehicles. One component of this quest is reducing the amount of energy needed to combat wind resistance. At 70 miles per hour, about 65% of the total energy output from a typical heavy-duty truck engine goes to simply overcoming aerodynamic drag. One big reason air resistance is so high is the presence of a large radiator directly in front of a truck's engine to maximize the cooling effect of onrushing air.

The large radiators are needed because of the type of fluids that circulate in cooling systems, drawing heat from the engine and transporting it to the radiator, where it can be released to the surrounding air. These fluids are chosen, in part, because they have high heat capacities, which means that they can absorb a lot of heat while their temperatures increase only minimally. The fluids, however, also absorb and release heat very slowly. It's the slow release of heat that accounts for the size and positioning of vehicle radiators. If the fluids could conduct heat more quickly, radiators could be made smaller and configured to allow for highly streamlined designs. As a bonus, you wouldn't need as much fluid to do the same job, so coolant pumps could be reduced in size. Or truck engines could be operated at hotter temperatures to provide more horsepower while still meeting stringent emission standards. High-conductivity coolants also would be ideal for advanced fuel-cell and hybrid-electric vehicles, in which they could help keep running temperatures low.

Argonne researchers are developing a way of giving traditional engine coolants the high thermal conductivities they need, without adversely affecting their thermal capacities. The researchers discovered that dispersing small amounts of solid particles in the fluids boosts their thermal conductivities by unexpectedly large amounts. The trick is to use particles that are no larger than tens of nanometers in size. The result is a new class of heat-transfer fluids, called nanofluids. Because the particles are so small, nanofluids aren't plagued by settling problems, whether or not dispersants are used, so they will not cause clogging — even with microchannel heat-transfer devices.

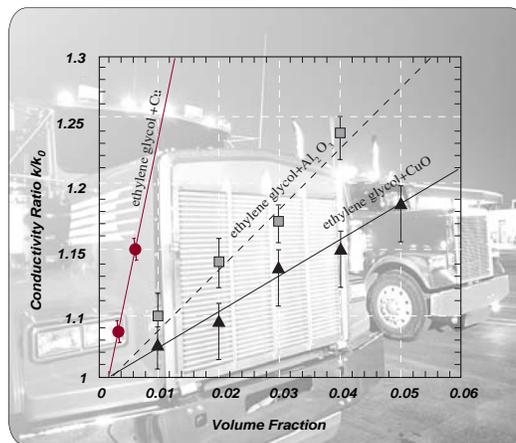
Funded by the U.S. Department of Energy's Office of Heavy Vehicle Technologies, Argonne is collaborating with the Valvoline Company to develop nanofluid coolants and lubricating oils for truck engines. Already the researchers have demonstrated that the thermal conductivity of ethylene glycol increases by up to about 20% when a small volume (4%) of cupric oxide nanoparticles (with an average diameter of 35 nm) is dispersed in it. A similar gain was seen in a study involving aluminum oxide nanoparticles dispersed in water.

More recently, Argonne found that nanofluids consisting of copper nanoparticles dispersed in ethylene glycol show much higher thermal conductivities than do either pure ethylene glycol or ethylene glycol containing the same volume fractions of dispersed oxide nanoparticles.

The discovery that adding nanometer-size particles to traditional heat-transfer fluids dramatically increases their thermal conductivity is as yet without a theoretical explanation, so getting a better basic understanding of the phenomenon is one goal motivating the Argonne research program. Another is to develop economical ways of producing nanoparticles in production-scale batches. Argonne researchers now use a one-step

procedure for producing nanofluids based on metallic particles and a two-step procedure for oxide-based nanofluids. Both techniques are relatively straightforward and hold the potential for economical batch production.

As a spin-off from the nanofluid research, Argonne has been looking at the effect of soot in engine oil. Soot accumulates in engine oil over time in amounts that are expected to increase dramatically as engine designers resort to using exhaust gas recirculation to limit exhaust emissions. Even though soot particles are not as small as those in nanofluids, the researchers found that their accumulation in engine oil leads to a 15% increase in thermal conductivity and an increase in the oil's lubricating properties, as well. The former finding opens the door to development of a sensor that monitors engine performance by measuring thermal conductivity increases as soot builds up inside an engine.



Metallic nanofluids show dramatic enhancements in thermal conductivity compared with nanofluids based on oxide particles.

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Zeroing in on Diesel Particulate Emissions

Thick clouds of soot particles no longer billow from new bus and truck exhaust pipes, thanks to today's advanced diesel engines, which emit fewer and smaller particles. Nevertheless, scientists and engineers need to continue studying ways of further improving diesel performance, because small soot particles may pose greater health concerns than the large particles emitted from older engines.

As a result of the relatively recent discovery that emitted particles vary greatly in shape, microstructure, and chemical composition as engine operating conditions change, researchers at Argonne have mounted a major effort to learn how particles form inside diesel engines. Their goal is to achieve a fundamental understanding of how engine speed and load conditions influence the particle formation process — which will help them develop effective ways of significantly reducing diesel particulate emissions.

With funding from the U.S. Department of Energy's Office of Heavy Vehicle Technologies, Argonne used transmission electron microscopy (TEM) to inspect individual soot particles, which, at the ultrahigh magnification of TEMs, was a lot like finding a few needles in hundreds of haystacks. The researchers discovered that at low operating conditions (675 rpm/0% load to 1,400 rpm/15% load), the particles tend to stick together and have nebulous boundaries because of liquid constituents that make the particles merge with one another. At higher engine operating conditions (e.g., equal to or higher than 1,400 rpm/50% load), the particles appear more solid, and the boundaries between them become more pronounced.

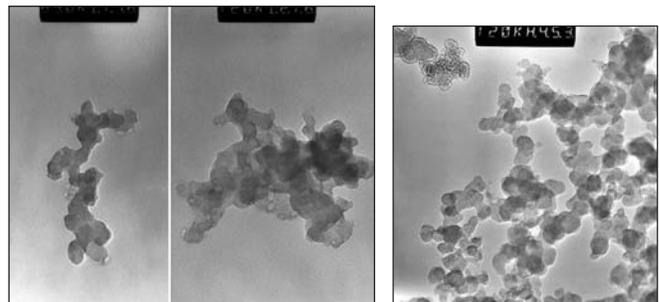
Preliminary chemical analysis showed that emitted particles contain more chemical components at lower speeds and loads because, at the low temperatures involved, several of the chemical constituents of diesel fuel don't evaporate or react completely. The particles were found to contain more potential cancer-causing pollutants — specifically, more polycyclic aromatic hydrocarbons (PAHs). At high engine operating conditions, the particles were found to consist mostly of carbon in the form of graphite. This means that when diesel trucks or buses are driven on the highway, they most likely produce graphitic particles, but in the downtown areas of major cities, they tend to produce particles that contain both graphitic and hydrocarbon components, including possibly harmful PAHs. The researchers also discovered that diesel soot particle formation is controlled by a mechanism that induces small nucleus-containing particles to join together, forming long chain-like particles that are emitted into the atmosphere.

The current research program extends this initial work to include the full range of engine operating conditions encountered in city and highway driving. Use of TEM continues,

because it provides the most accurate way of measuring particle size. The method is being supplemented, though, with two quantitative techniques for measuring the chemical compositions and physical phases of the emitted particles. The latter measurements are being made in partnership with researchers at the University of Illinois at Chicago and Drexel University.

The University of Illinois at Chicago has a two-laser ion trap mass spectrometer that can provide information not only about the atoms that are present, but direct information concerning the chemical compounds, too. The collaboration with Drexel University involves using Raman scattering spectroscopy to determine what portion of the particles is graphitic and what portion is in the liquid phase.

The Argonne researchers are currently studying the particles that come directly from diesel engines; they also plan to study tailpipe emissions and the influence of sulfur-based impurities in diesel fuel, because there is considerable evidence that sulfur content contributes significantly to particle formation. The research could lead to important applications, given that manufacturers of emission abatement technologies need highly accurate information on particle size and chemical composition to design practical and effective aftertreatment systems.



900 rpm, 15% load and
1400 rpm, 15% load

1400 rpm, 50% load

Emitted diesel particles vary greatly in shape, microstructure, and chemical composition as engine operating conditions change. Understanding how speed and load influence particle formation could help researchers develop ways to reduce diesel particulate emissions (images not to same scale).

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On January 9, at the Detroit Auto Show, U.S. Department of Energy (DOE) Secretary Spencer Abraham announced the kickoff of the new FreedomCAR program — a partnership between DOE and U.S. automakers to develop hydrogen as a primary fuel for cars and trucks. The goal of the program, which improves upon the Partnership for a New Generation of Vehicles (PNGV) program, is the development of cars and trucks that are more efficient, cheaper to operate, pollution-free, and competitive in the showroom.

During his speech, Secretary Abraham stated, "My enthusiasm was given a boost last summer when I toured the Department's Argonne National Lab near Chicago, to see its work on fuel cells. A first-generation fuel cell...took up an entire wall. But now you can see we have developed fuel cells that are much smaller but just as powerful ... And they're getting smaller and more economical all the time."

Working to reduce the size and increase the power of fuel cells is not the only way Argonne will contribute to the FreedomCAR program. As the article on page 2 describes, Argonne will be involved every step of the way in helping make fuel-cell vehicles a reality — addressing hydrogen production, analyzing the total cost of producing and using hydrogen, studying the obstacles to a hydrogen infrastructure, and modeling and testing fuel-cell vehicles.



Dan Santini stepped down as chairman of the National Research Council's Transportation Research Board's (TRB's) Alternative Fuels Committee after serving two three-year terms — the maximum allowed by TRB. During Dan's terms, the committee adopted a double-blind review policy more stringent than the TRB's single-blind approach; initiated a second set of summer meetings in the eastern U.S. to complement the committee's long-standing "Asilomar" summer conference meetings (held biennially in California); and, jointly with the Energy Committee, established an International Subcommittee.

Ali Erdemir, of Argonne's Energy Technology Division, served as the Conference Chairman for the 2001 Annual Meeting of the Society of Tribologists and Lubrication Engineers in Orlando, Florida. He was responsible for coordinating technical and logistic issues to ensure the success of the conference, which was rated as one of the best in the last 10 years. The conference, which was attended by more than 1,500 engineers and scientists, featured eight education courses, a large exhibit (by 150 companies), and more than 300 technical papers.

As Secretary Abraham pointed out in his speech, a gradual switch to a hydrogen economy would mean "we will no longer have to depend so heavily on imported oil from unstable regions of the world."

Researchers like Dan Santini here at Argonne (see page 4), who developed two practical models to predict oil price shocks and recessions, have illuminated how dangerous such dependence can be. An important emphasis of Dan's theory is the effect of the transportation sector — which consumes 67 percent of all the petroleum Americans use — on the U.S. economy.

The nanofluid research described on page 5 will lead to high-conductivity coolants that would be ideal not only for improving the fuel economy of large diesel trucks, but also in advanced fuel-cell and hybrid-electric vehicles, in which they could help keep running temperatures low.

The goal of the particulate research described on page 6 is more short term: developing effective ways of reducing diesel particulate emissions will help address concerns about the heavy trucks that populate today's roads.

As Secretary Abraham remarked during his speech, "Although we are a buyer on the world market, we are a buyer with choices. And one of those choices is to use the technological genius found in private industry and at our national laboratories to invent our way to energy independence."

A study coauthored by Argonne's **Michael Wang and Donquan He** and experts at General Motors and three major energy companies (BP, ExxonMobil, and Shell) has been recognized as an outstanding accomplishment by the General Motor's Research and Development organization and recently received a Special Achievement Award for 2001. The landmark study, entitled *Well-to-Wheel Energy Use and Greenhouse Gas Emissions of Advanced Fuel Vehicle Systems — North American Analysis*, has been widely cited and is considered by many to be the "gold standard" against which future similar studies will be benchmarked. The study was featured in a Patrick Bedard column in the March issue of *Car and Driver Magazine*.

Chris Saricks was recently elected Chair of the Transportation Issues Division of the Air & Waste Management Association's Technical Council. In that capacity, he participated in an organizational meeting conducted in Baltimore, Maryland, November 1-4, 2001, for the purpose of programming paper and panel sessions for the Association's 95th Annual Meeting and Exhibition in Baltimore, to be held June 23-27, 2002.



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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