e-lab

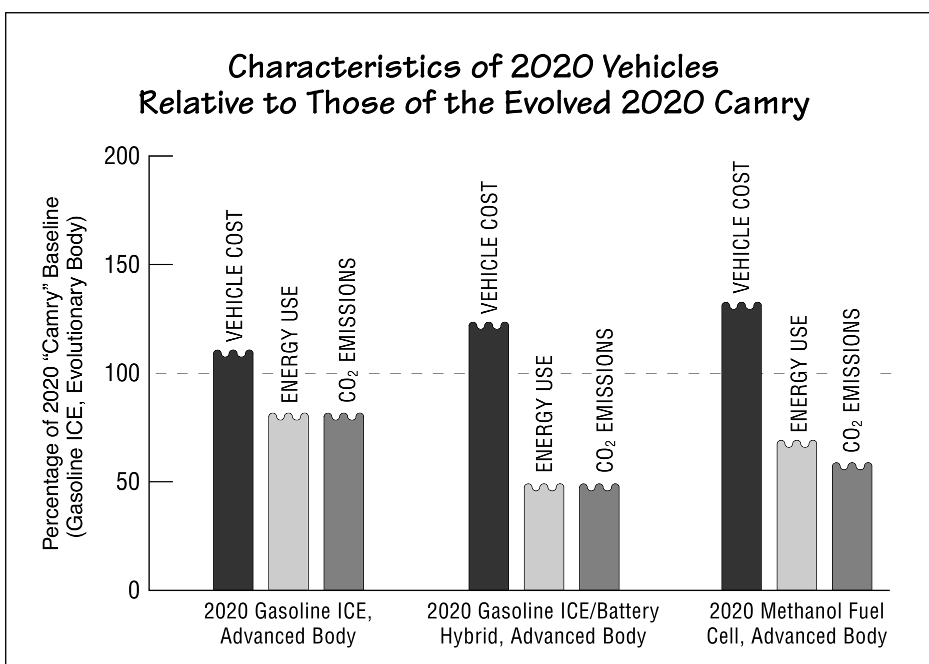
Energy Laboratory research and related activities at the Massachusetts Institute of Technology

October–December 1999

Fuels and Vehicles for 2020: How the New Technologies Measure Up

An Energy Laboratory assessment of likely new technologies for passenger cars in 2020 has come up with no overall winners in the race for cars with lower greenhouse-gas and other emissions. Initial results from the assessment show that the gains from continued work on conventional fuels and vehicles are so great that emerging technologies like the fuel cell will have trouble competing. By 2020, conventional vehicles will be twice as efficient, half as polluting, and cost little more. New technologies will provide somewhat greater efficiency and emissions gains but at a much higher cost. With little or no private benefit to purchasers, the new technologies are unlikely to succeed in the marketplace unless government action or public pressure calls for major reductions in greenhouse-gas emissions. The MIT researchers compared the technologies using data from various sources, adjusted so that key assumptions were consistent. Calculations included energy use and emissions not only from driving the vehicle but also from making and delivering the fuel—a change that dramatically reduced the attractiveness of some technologies. The assessment examined how vehicle purchasers, fuel manufacturers, vehicle distributors, and all other major "stakeholders" would trade off dozens of characteristics of different technologies, from cost and safety to convenience and familiarity. The analysis confirmed that what is unimportant to one stakeholder group can be a real "showstopper" for another. Identifying critical showstoppers and developing strategies to overcome them is the researchers' ultimate goal. They are now completing their initial assessments and are beginning to examine other technologies, including biomass fuels and battery vehicles, and other types of vehicles, including light and heavy trucks.

Demand for road transportation is constantly growing, especially in developing countries with expanding economies. Yet the environmental consequences of even today's level of demand are



In this comparison, the baseline is a Camry-like car as it is likely to have evolved by 2020, with continued research to improve its fuel, power train, and vehicle body but no major breakthroughs. The three new vehicles all have advanced bodies, one powered by a gasoline internal combustion engine (ICE), one by a gasoline ICE/battery hybrid, and one by a methanol fuel cell. All three provide decreased energy use and emissions but at an increased overall cost to the purchaser. (See text on page 4.)

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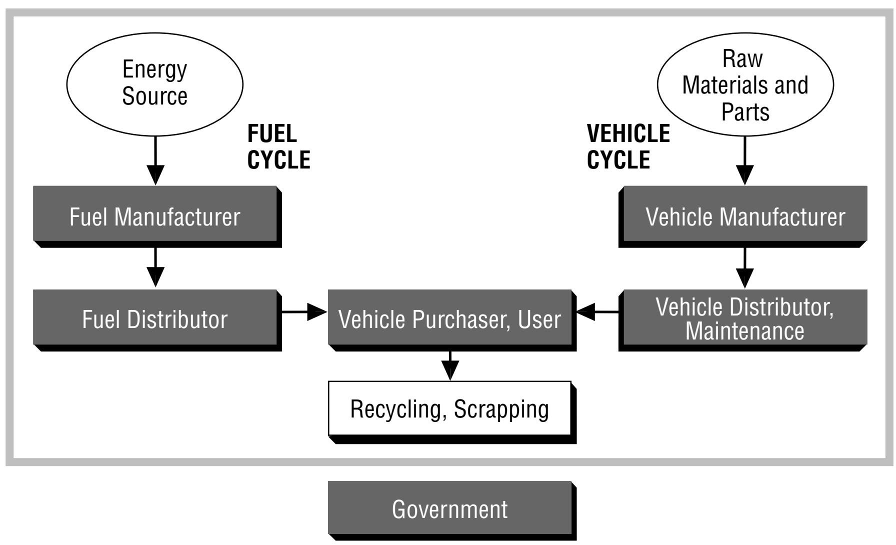
significant. In the United States, on-road vehicles emit huge amounts of greenhouse gases, including nearly a third of all domestic carbon dioxide (CO_2) emissions and about a fifth of global CO_2 emissions. Vehicles also emit large quantities of hydrocarbons, nitrogen oxides, carbon monoxide, and particulates, all of which pose local and regional environmental and health problems. The best way to reduce those emissions —and to meet new, stricter regulatory limits—may be by using new fuel and vehicle technologies. Many promising technologies are now being developed, and studies that examine and compare their costs and benefits abound. However, in many cases the data and assumptions on which those studies are based are inconsistent, incomplete, or unclear. Knowing which of the technologies are most likely to succeed is therefore difficult.

For the past year, Dr. Malcolm A. Weiss, Professor John B. Heywood, Dr. Elisabeth M. Drake, Dr. Andreas Schafer, Felix AuYeung, and Darian Unger have been assessing promising new road technologies using a methodology designed to be comprehensive, systematic, and easy to understand. The assessment covers various combinations of fuel and vehicle technologies over their entire life cycles; and it considers all characteristics of each combination from the perspectives of the organizations and people whose decisions influence its success or failure.

The figure on this page shows the system considered. The shaded boxes indicate the major stakeholders—groups of people with similar interests and values. The left side of the figure shows the fuel cycle. It starts at the energy source (the oil in the ground, the trees in the woods), moves through the fuel manufacturer (the refinery, the manufacturing plant), and ends with the fuel distributor, who delivers the fuel to the vehicle user. The right side of the figure shows the vehicle cycle. It starts with raw materials and parts (iron ore, scrap metal), moves through the vehicle manufacturer, and ends with the vehicle distributor, who sells cars to the vehicle purchaser and maintains and repairs cars for the vehicle user. The vehicle user operates the car throughout its lifetime and then disposes of it, recycling or scrapping parts as appropriate. Overseeing the entire system is the government, which has concerns about environmental, legal, infrastructure, and other issues.

Major Life Cycle Elements and Stakeholders Considered in the MIT Assessment of Technology Options for Road Transportation in 2020



The focus of the assessment is the year 2020—far enough ahead for new technologies to be developed and introduced but not so far that identifying the potential competing technologies is impossible. For the initial analysis, the researchers selected fuel and engine technologies that can be developed by 2020 with “reasonable diligence and effort” and no need for technical “breakthroughs.” Each new technology was assumed to make up a few percent of all the cars being sold in 2020—enough to benefit from most economies of scale. The initial assessment thus focuses on where we want to be in 2020 and ignores (for now) the possible difficulties encountered in getting there.

The technologies considered fall into three categories: fuels, power trains, and vehicle bodies. (Power trains include combinations of fuel systems, propulsion systems, and drive trains, which are used to transfer work from the engine to the wheels.) The specific technologies are listed in the table on page 3. Biomass fuels and battery vehicles were not included in the initial analysis because they are less likely to be developed and widely commercialized by 2020. Seven new technology options were defined, each employing a selected fuel and power train in a lightweight, “advanced” vehicle body that uses a new design and new materials, including abundant aluminum. In all cases, the vehicle's capacity, range, and performance were comparable to those of today's typical family car.

As a basis for comparison, the researchers defined a car similar to a Toyota Camry with a gasoline-fueled internal combustion engine (ICE), not as it exists today but as it is likely to have evolved by 2020. The cumulative effect of "evolutionary" changes in the fuel, power train, and vehicle body yields major advances similar to the advances of the past twenty years or so. The 2020 "Camry" has the same capacity, range, and performance as the 1996 Camry; but it weighs 22% less, uses half as much fuel, and emits half as much CO_2, all for a cost increase of just 5%, or $1,000 (in constant dollars).

For each technology option, the researchers estimated energy efficiency, CO_2 emissions, costs, safety and health effects, reliability, convenience, and other characteristics that can make or break a road technology. The full fuel and vehicle cycles were included (though energy use and emissions during the vehicle's manufacture were not accounted for in this initial assessment). Data came from recently published reports, follow-up interviews with authors, and selected unpublished studies. Rather than averaging data from different studies, the researchers used their experience and judgment to select data that appeared both reasonable and based on careful analysis. They used models developed at MIT and at ETH-Zürich to define the characteristics of vehicles.

The researchers then compared each of the seven new technology options with the 2020 Camry, one characteristic at a time. Evaluations for a given characteristic could range from much more favorable to not materially different to much less favorable. The outcomes of such comparisons can vary substantially among the stakeholder groups, and a negative evaluation by just one group can kill a new technology. Therefore, the researchers made up a large grid, or "template," for each stakeholder group showing how that group evaluates more than thirty characteristics of each new technology option, as compared to the base case 2020 Camry. A supporting template explains every evaluation in a few words.

Given the mass of information and opinions, the researchers do not attempt to summarize the collected data or to aggregate it in order to merit-rate or rank the technologies. However, they do make several generalizations that they believe will hold up as they continue to gather additional data. For example, the assessment shows clearly that comparisons based on published studies must be treated cautiously. Studies are often based on assumptions and constraints that are inconsistent or not explicitly defined. As a result, outcomes can vary widely. For example, estimates of the amount of energy consumed in the fuel cycle varied from study to study by more than a factor of two.

Significantly, some studies leave out the fuel cycle entirely. Yet reliable data show that the energy consumed in making and distributing fuel can be a large fraction of the energy consumed when using the fuel to run the vehicle. For example, several studies conclude that a provider of methanol or hydrogen made from natural gas uses well over half a megajoule of energy to make each megajoule of the fuel ultimately delivered to the customer. Leaving out the fuel cycle can therefore alter the efficiency rankings of various technologies. One study compares the fuel efficiency of five technologies. When the fuel cycle is excluded, the hydrogen-based fuel cell is most efficient. When the fuel cycle is included, a diesel ICE is best. The methanol-based fuel cell is second best when the fuel cycle is excluded but last when fuel cycle is included. Thus, comparisons of technologies can be misleading if the technology assessments do not use a "well-to-wheels" approach that includes both the fuel and vehicle cycles.

Technologies Examined to Date

Fuels:	Evolved gasoline from crude oil Evolved diesel from crude oil Fischer-Tropsch diesel from natural gas Methanol from natural gas Hydrogen from natural gas
Power trains:	Gasoline direct-injection internal combustion engine Diesel direct-injection internal combustion engine Fuel cells Mechanical drive trains Electrical drive trains Hybrid drive trains
Bodies:	Advanced Evolutionary

The MIT assessment also demonstrates the importance of evaluating technologies from the perspectives of different stakeholders. Where one stakeholder group sees advantages, another may see enormous barriers—and another may be totally indifferent. As an example, the researchers considered how several stakeholder groups might view methanol-based fuel cell vehicles compared to the 2020 Camry. The government would strongly favor the fuel cell vehicle because it would cut CO_2 emissions in half (per kilometer driven) and reduce other air emissions to negligible values. Fuel suppliers, on the other hand, would need to invest $12–15 billion to supply enough methanol to equal 5% of today's US gasoline energy; and most of the investment would have to be in remote locations abroad, where natural gas is relatively inexpensive. The risk would be enormous. Finally, from the vehicle owner's point of view, there is no incentive to buy such a car. Fuel savings would be trivial. In 2020, as today, the cost of buying fuel (not including taxes) will be a negligible part of the cost of owning a car; so any potential fuel savings will not influence the consumer's technology choice. But buying a fuel cell vehicle would cost over $26,000—far more than the $20,000 Camry.

Indeed, there appears to be no economic reason for US consumers to demand any of the new technologies and therefore no reason for manufacturers to make them or for distributors to offer them. New fuel and vehicle technologies may reduce environmental insults, but the consumer must pay the extra cost while receiving little direct private benefit. The figure on page 1 compares three advanced-body 2020 vehicles with the evolved 2020 Camry on the basis of three characteristics: vehicle cost, energy use, and CO_2 emissions. (The tops of the bars are corrugated to imply that these numbers are estimates.) The 2020 advanced-body gasoline ICE vehicle costs a little more than the 2020 Camry but will cut energy use and CO_2 emissions. The gasoline hybrid (a gasoline ICE supplemented by a battery) costs still more but reduces energy use and CO_2 emissions still more. The methanol fuel cell vehicle costs still more; and energy use and CO_2 emissions are not quite as good, although the differences are within the uncertainty of the results. The evolved 2020 Camry is hard to beat, and the incentive to invest in the new technologies simply is not there. Thus, it seems unlikely that these new technologies will enter the market unless the government takes action to provide the needed incentive—or unless purchasers come to believe that the extra cost is worthwhile for the public benefit.

Of all the engine-fuel combinations considered, the researchers found no single technology that proved an across-the-board winner in 2020. The diesel hybrid looks best for high efficiency and low CO_2 emissions, but it is not clear that particulate and nitrogen oxides emissions from diesels can be reduced enough to meet likely future regulatory standards. The hydrogen-based fuel cell—a favorite of many people—actually appears less attractive than the diesel hybrid. Its efficiency and emissions characteristics are comparable, but it would cost more and its adoption would require major infrastructure changes to make compressed hydrogen widely available. However, special opportunities may arise for certain technologies. For example, hydrogen fuel cells may be adopted in urban buses—a situation where a single station for manufacturing and compressing hydrogen could serve a whole fleet of vehicles.

In the longer run—say, 50 years—hydrogen-powered fuel cell or battery vehicles would be attractive goals, but developing those technologies will involve overcoming formidable technical and economic obstacles. The researchers stress that research activities in the near and intermediate term should be consistent with long-term goals. For example, devoting considerable resources to developing electrical drive trains is appropriate. Electrical drive trains are used in hybrid systems, which promise substantial gains in energy use and emissions well before 2020. Likewise, electrical drive trains are used in both fuel cell and battery vehicles. Developing and introducing electrical drive trains would therefore serve both intermediate-term and long-term needs.

The researchers are now revising and completing their data tables and templates through further analyses of the literature and through discussions with various experts. They will consider other emissions and other technologies, including biomass fuels and battery vehicles; and they will examine not just passenger cars but also sport utility vehicles and light and heavy trucks. Based on their systematic analysis of stakeholder reactions and attitudes, the researchers hope they can design strategies for overcoming critical barriers that may otherwise keep promising new fuel and energy technologies from succeeding in the marketplace.

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Regulating Hazardous Air Pollutants in Urban Areas: Recommendations from Energy Laboratory Symposium

In July 1999, an Energy Laboratory symposium of scientists, regulators, and industry and public interest representatives examined the scientific challenges posed by the US Environmental Protection Agency's new Integrated Urban Air Toxics Strategy. This strategy describes EPA's plans for substantially reducing public health risks in urban areas from air toxics, or "hazardous air pollutants" (HAPs), a wide-ranging group of emissions that cause cancer or other health problems and are emitted by cars, smokestacks, dry cleaners, auto body shops, and many other sources. ("Criteria" pollutants such as ozone and sulfur dioxide are regulated separately.) Symposium participants recommended continuing research on sources of HAP emissions; on processes whereby HAPs change in the atmosphere; on routes by which HAPs enter the human body; and on health effects, including the effects of exposure to multiple HAPs and of variations among individuals. Other recommendations included revising EPA's plan to monitor many HAPs in many locations. Monitoring should instead focus on critical HAPs in selected areas and on sources that are controllable. More attention should be given to indoor air pollution, the primary health risk for many people. Work to identify the dangerous constituents in diesel exhaust should continue, but tighter restrictions on overall diesel emissions are probably warranted now. High priority should be placed on controlling mercury emissions, especially from electric power plants. Finally, EPA should communicate better, both with the general public and with state officials, who have the most experience with data and programs particular to their regions.

For decades, attention has focused on controlling criteria air pollutants such as nitrogen oxides, sulfur oxides, ozone, and particulates. But another class of air pollutants—the air toxics, or hazardous air pollutants (HAPs)—is coming under increasing scrutiny. Among the HAPs are benzene, mercury, formaldehyde, and a host of less-familiar-sounding chemicals that are known or suspected to cause cancer or other serious health effects. During the past decade, the Environmental Protection Agency (EPA) has issued regulations that have substantially reduced emissions of HAPs from cars, trucks, fuels, and industries such as chemical plants and oil refineries. However, concern continues to focus on urban areas, where populations are high, emissions sources are many and varied, and emissions from even small sources may combine to have unexpectedly significant health impacts.

In mid-1999, EPA released its Integrated Urban Air Toxics Strategy, a plan that complements existing air toxics regulatory programs and focuses specifically on protecting human health in urban areas, as instructed in the Clean Air Act Amendments (CAAA) of 1990. The strategy is an unprecedented move for EPA: instead of presenting a set of rules and regulations, it describes objectives, priorities, and schedules for ongoing actions that will reduce public health risks from HAPs in urban areas. Included are steps to improve EPA's understanding of health risks posed by urban air toxics, programs to determine what pollutants are present, and initiatives to address specific pollutants and specific community risks. Finally, the strategy calls for education and outreach efforts to inform stakeholders and the public about the strategy and to get input into designing programs to implement it.

In July 1999, the Energy Laboratory hosted a two-day symposium to discuss scientific aspects of the Integrated Urban Air Toxics Strategy. The symposium was part of a series of annual conferences begun in 1993 for the purpose of informing decisionmakers about scientific aspects of important air pollution issues and improving communication between the scientific and regulatory communities. Participation at the 1999 symposium was limited to invited members of the scientific, regulatory, industry, and public interest communities. Together, this group examined the requirements and challenges of the air toxics strategy and proposed specific recommendations on how best to implement it.

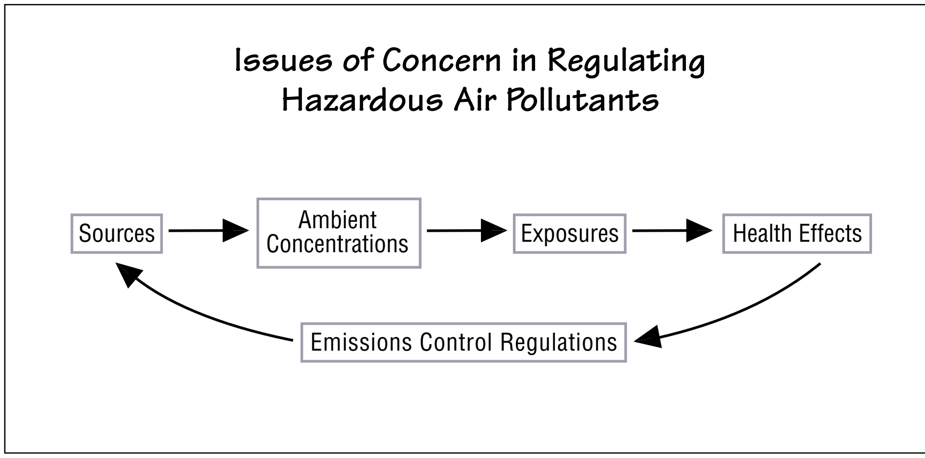
Included in the strategy are lists of 33 HAPs and 29 types of sources that EPA regulates or has plans to regulate. While those lists were based on extensive analyses of available data, further studies are needed to confirm whether the existing and planned regulations are sufficiently strict and whether additional targets should be added. Presentations and discussions at the symposium outlined the scientific challenges involved in that task. The figure on page 6, presented at the symposium, shows the components that must be considered and serves as a basis for understanding the difficulties involved at each step.

Sources. HAPs may come from "point" sources (typically smokestacks, which emit large quantities of HAPs), "mobile" sources (all types of vehicles), and "area" sources (dry cleaners, gas stations, and other small but ubiquitous sources that together contribute significant quantities of urban emissions). The Integrated Urban Air Toxics Strategy looks collectively at all three types of sources but focuses particularly on area sources because of the regulatory challenge they pose. A given HAP may originate from many types of sources, both outdoors and indoors; and a single source may emit many types of HAPs. In addition, some HAPs form in the atmosphere from chemical reactions of other substances, making them particularly hard to control.

Ambient Concentrations. Predicting the chemical makeup of the atmosphere is difficult because many emitted HAPs transform in the atmosphere. They may degrade into nontoxic components or react to form products that are more hazardous than the emitted substances. Most atmospheric “transformation products” remain unidentified. Some HAPs (for example, mercury) ultimately settle onto the earth’s surface and can enter the food chain via non-inhalation routes. And some HAPs occur indoors more than outdoors. Programs to monitor ambient concentrations can provide important insights, but questions abound. What should we measure and where? Should we measure where sources are abundant or where populations are high? And how do we ensure that consistent monitoring techniques are used in all locations?

Exposures. Most human exposures to HAPs occur through breathing, but eating and touching are also important exposure routes. The level of exposure depends not only on ambient pollutant concentrations but also on personal behavior. A person who pumps gasoline will have higher exposures to escaping benzene vapors than will a person who just stops to buy gasoline. And a person who spends little time outdoors will be exposed mostly to indoor pollutants.

Health Effects. Primary concern focuses on cancer-causing pollutants, but HAPs are also associated with neurological, reproductive, and developmental disorders. Establishing whether an air toxic threatens health is difficult. One problem is variability in the population. One person may be unharmed by a particular HAP, while another may react to low levels of the same substance. There may be “cumulative” effects from exposure to several substances that cause the same type of damage. And there may be “synergistic” effects. Two substances may be minimally hazardous by themselves. But when both are in the body, one substance may prime the body to be more sensitive to the other. An added problem for researchers is how to quantify health effects when they occur. Methods exist for calculating the carcinogenicity of a substance, but quantifying and comparing the seriousness of widely varying non-cancer effects remain difficult.



The US Environmental Protection Agency is planning new and stricter limits on emissions of hazardous air pollutants from a variety of sources in urban areas. Setting appropriate and effective limits on specific sources is a challenge, however, as the process that links emissions sources to health effects is complex. This figure shows key steps in the process that need clarification. (See the text on pages 5 and 6.)

Emissions Control Regulations. Clearly, the process by which emissions from specific sources ultimately cause health effects is extraordinarily complex. A better understanding of the various steps in that process and how they are linked would permit EPA to set more effective and appropriate emissions control regulations back at the source.

Presentations at the symposium showed that researchers still need to develop data, to understand processes and mechanisms, and to address uncertainties at each step in order to design better control strategies for various sources. Major challenges include defining a prioritized research agenda and designing and implementing appropriate regulatory actions in the near term, while knowledge is still evolving. Resources—both financial and human—are limited, so every research task or policy undertaken has an implicit trade-off. Undertaking one activity precludes undertaking another one. With that limitation in mind, symposium participants made several recommendations.

Most notable was their criticism of EPA's proposed emissions monitoring program, which calls for all 50 states to monitor HAPs. The participants recommended that EPA not try to measure everything everywhere but instead carefully plan a monitoring program with clear objectives and priorities. The first task should be to analyze the abundant data that have already been collected but not yet thoroughly examined. The monitoring program should be designed to fill the gaps and should be based not on political pressures but on scientific and regulatory objectives. The focus should be on compounds most relevant to health, on sources where emissions control is feasible, and on locations carefully selected to contribute to scientific understanding. In addition, EPA should begin taking a holistic approach to monitoring. For instance, under EPA's program to reduce criteria pollutants, states are monitoring sources of particulate emissions. Many HAPs come from the same sources, but there is as yet no provision for coordinating the particulate and HAPs monitoring programs—a step that would increase efficiency and reduce cost.

Participants generally agreed that insufficient attention is given to indoor air pollution. Almost all monitoring takes place outdoors. Yet there are significant indoor sources of HAPs; concentrations of many HAPs are higher indoors than outdoors; and people spend a lot of time indoors. (In fact, many people spend less than one hour outside each day.) Participants therefore recommended that EPA revise its monitoring program to include analysis of indoor air quality and indoor sources of contaminants.

Another area that needs more attention is emissions from the diesel engine. Considerable evidence already suggests that diesel exhaust causes adverse health effects. But diesel exhaust is a complex mixture of particles, gases, and vapors; and it is not yet clear which constituents threaten health. Symposium participants agreed that more research is needed to identify those constituents and to understand their impacts.

However, they disagreed as to what regulatory steps should be taken now. EPA has described plans to tighten regulations on diesel exhaust. The new regulations would continue EPA's practice of testing and regulating diesel exhaust as a single entity—an unusual approach, as most regulations focus on individual compounds rather than mixtures. Some participants recommended that EPA wait until the offending constituents are identified so that targeted control strategies can be developed. They also pointed out that existing regulations are already substantially reducing emissions from diesels and that taking further (perhaps unwarranted) action could threaten the future viability of this fuel-efficient engine technology. Other participants argued that testing and regulating real-life mixtures is "good regulatory science." In their view, EPA should take further regulatory action now; and scientists should continue to investigate the health impacts of diesel exhaust.

In contrast, the need to control mercury emissions was unquestioned. Mercury is the only HAP on EPA's list that threatens people primarily by ingestion rather than inhalation. It is a powerful neurotoxin that is neither created nor destroyed by combustion or atmospheric reactions. Airborne mercury settles on land or water and ends up highly concentrated in plants and animals that humans eat. Forty states have issued fish consumption advisories because of mercury contamination of freshwater and marine fish.

EPA considers mercury from coal-fired power plants the HAP of greatest potential concern. Mercury occurs as a vapor in flue gases at the part-per-billion level, so control is difficult. Also, because concentrations are so low, mercury does not appear in official reports of toxics releases filed by utilities. Symposium participants supported EPA's plans to require more stringent reporting of mercury emissions. Electric power experts described control strategies now being developed but emphasized that many engineering aspects are not yet well understood. Control of mercury from power plants may be achieved within three to five years, but the task will be difficult.

Medical and municipal waste combustors are other major sources of mercury. Here the news is more encouraging. Hospitals continue to rely on mercury in thermometers, switches, and other devices that sense small temperature changes. Nevertheless, a mercury-control program in New Jersey has eliminated up to 99% of the mercury occurring in exhaust from medical waste incinerators, largely by focusing on hospitals' use of mercury-containing devices. The program has also substantially reduced mercury emissions from municipal waste combustors. Symposium participants recommended that

EPA take more aggressive steps to get mercury out of consumer products.

Participants also advised EPA to work harder at communicating with the public. People have pragmatic concerns such as whether eating vegetables from a roadside garden is safe. Abstract statistics from formal risk assessments are of little use to them. Informing the public about research findings and regulatory plans in an understandable way could ease political pressures on EPA and the states to take actions that may not be warranted scientifically. Communication between EPA and the states should also be improved. Representatives from state environmental offices would like to take a more active role in EPA's conceptual planning. In general, EPA tells the states what, where, and when to monitor. Yet state officials know best what monitoring is already going on, what the primary concerns are in their region, and what resources are available without having to divert funds from higher-priority activities.

In general, symposium participants recognized the need for additional air toxics research and regulation. A few participants recommended keeping concern about air toxics in perspective. One demonstration showed that only a small fraction of all deaths from cancer is attributable to air toxics. However, other participants expressed concern that air toxics pose a significant health risk and deemed them a "sleeping giant." For years, EPA has focused on the criteria air pollutants—first carbon monoxide, then ozone, and most recently particulates. In response to EPA mandates, states have put substantial resources toward meeting standards for those pollutants. Meanwhile, the air toxics have been largely overlooked. Given the potentially serious health impacts of air toxics, allocating more resources to controlling these "poor cousins" of the criteria pollutants may well be warranted.

This article is based on a summary of the 1999 Urban Air Toxics Summer Symposium that was prepared by Renee J. Robins, program coordinator for MIT's Integrated Program on Urban, Regional, and Global Air Pollution. The summary is available as a pdf file at the Energy Laboratory's home page, located at <http://web.mit.edu/energylab/www/> (see reference 1). The symposium was held at Endicott House in Dedham, Massachusetts, on July 8–9, 1999. It was funded by the MIT Energy Laboratory, MIT Center for Environmental Initiatives, EPA Center on Airborne Organics, EPA Office of Research and Development, Northeast States for Coordinated Air Use Management, California Air Resources Board, The Health Effects Institute, Mickey Leland National Urban Air Toxics Research Center, US Department of Transportation Volpe National Transportation Systems Center, American Petroleum Institute, Chevron, British Petroleum, Amoco, Sun Oil Company, Engine Manufacturers Association, Chemical Manufacturers Association, Electric Power Research Institute, and Pennsylvania Power & Light Company.

News Items

On October 28–29, the **Center for Energy and Environmental Policy Research** (CEEPR) held its **fall workshop**. Topics included pricing and strategic behavior in electricity markets, spot and future price dynamics of the oil complex, the debate over oil supply, global warming detection and attribution, an update on Title IV as the United States moves into Phase II, and the comparative merits of transmission companies and independent system operators for providing transmission services. Seventy-five representatives from industry, government, and academia attended. Guest speakers were Lawrence S. Bacow, chancellor of MIT and Lee and Geraldine Martin Professor of Environmental Studies, who described environmental activities at MIT, and Institute Professor John M. Deutch, who discussed international security and energy issues.

On November 17–19, the **Joint Program on the Science and Policy of Global Change** held its fifteenth **Global Change Forum**, "**Definitions, Measurement, and Monitoring in Climate Policy**," in Boston, Massachusetts. Topics included the detection of climate change and calibration of climate models; the measurement, monitoring, and enforcement of carbon sinks; interpretation of "dangerous" as used in the Climate Convention; the use of global warming potentials in climate agreements; the interaction of air pollution control and global change; and measurement and implementation in national permit trading systems. Keynote addresses were given by Dr. Jonathan Pershing, head of the Energy and Environment Division of the International Energy Agency, and Dr. Rajendra K. Pachauri, director of the Tata Energy Research Institute in New Delhi. Meeting participants included about 135 representatives from industry, government, and academia, worldwide. The sixteenth forum will be held in Berlin on June 21–23.

Felix AuYeung, a graduate student involved in the Energy Laboratory assessment of new fuels and vehicles for 2020 (see article on page 1), is also a member of the **MIT Solar Electric Vehicle Team** (SEVT) that designed and built the "**Manta GTX**" solar car that took first place in its class at the World Solar Challenge '99. The 3010 km race from Darwin to Adelaide across the continent of Australia occurred on October 17–26. The Manta GTX finished first in the "cut-out" class and was top finisher from the United States and top finisher using lead-acid batteries. The cut-out class was designed for solar car teams that also competed in the US race Sunrayce and includes specific limitations on the solar-array size and types of allowable batteries. The Manta GTX carries relatively inexpensive Trojan lead-acid batteries and 14%-efficiency Siemens solar cells and is valued at $100,000—well below the top-finishing vehicle from the Australian Aurora team, which is valued at $2,000,000 (US dollars). The World Solar Challenge is a biennial event that attracts competitors and media from around the world and promotes teamwork, communication, and education through friendly competition. The MIT team included 13 students working with trip advisor Gill A. Pratt, assistant professor of electrical engineering and computer science, under the auspices of the MIT Edgerton Center.

Energy Laboratory researcher **Marija Ilić** is a key contributor to a recently released book, ***Unlocking the Benefits of Restructuring: A Blueprint for Transmission***. The book, published in November by Public Utilities Reports, Inc., presents the latest thinking on how to ensure that transmission systems operate more efficiently and receive the same benefits from competition gained by other components of the electric power sector. The book is a product of active collaboration among some of the foremost experts on economic regulation, business and finance, and power systems engineering. On the power systems engineering side, the book's contributors include Dr. Ilić of the Energy Laboratory; Lester Fink, a retired KEMA, Inc., power expert; and Charles Falcone, formerly senior vice president at American Electric Power. Addressing economics and regulatory issues are many noted economists such as Paul Kleindorfer of University of Pennsylvania, Michael Crew of Rutgers University, Shmuel Oren of University of California at Berkeley, and Ingo Vogelsang of Boston University. Representing finance and industry are Leonard Hyman of Salomon Smith Barney and Andrew Vesey of Ernst & Young LLP, who along with Shimon Awerbuch, an independent economist, edited the publication.

The provision and pricing of transmission services raise several challenges for the electric industry. Regulations now require open access to transmission services for all potential system users, both utility-owned and non-utility owned, including not only generators but also power brokers and those who serve specific loads. However, existing transmission lines were originally designed to deliver electricity from the power plants of a monopoly company to its own customers. Moreover, under open access regulation, the administrative and ownership boundaries that evolved under monopoly regulation are no longer recognized. The challenge to future transmission providers is to serve everyone in a nondiscriminatory manner while becoming sustainable businesses themselves.

A Blueprint for Transmission takes a systematic look at critical aspects of this challenge. The book is organized according to the types of problems studied; yet it recognizes that the technical, regulatory, and economic problems are interrelated. Establishing those interrelationships is a unique feature of this book. Specific topics addressed include the basic function, regulatory policy, and structure of the transmission "business" in a competitive market (Chapter 2); possible approaches to establishing Independent Transmission Companies (ITCs), including such aspects as finance, business organization, and regulation (Chapter 3); ITC strategies and organization (Chapter 4); and novel technical frameworks for transmission operation under open access (Chapter 5). The envisioned ITC would allow for alternative price and profit regulation (Chapter 6), including balanced incentives via innovative ratemaking (Chapters 7 and 8).

The book's successful integration of these disparate disciplines demonstrates the need for—and value of—such multidisciplinary collaboration. Studies of the electric power industry can no longer be undertaken by engineers, economists, and regulatory experts separately. Solutions and progress will result only from close collaboration among experts in all three fields. Activities at the Energy Laboratory support such collaboration and involve several contributors to the new book. Marija Ilić, Paul Kleindorfer, and Ingo Vogelsang are on the research team of a new MIT/ABB initiative entitled "Distribution Industry of the Future." Leonard Hyman has also been a frequent visitor and participant in Energy Laboratory workshops concerning new concepts and software for the electric power industry. Dr. Ilić and Stephen Connors, the co-principal investigators for the MIT/ABB initiative, plan to expand this innovative multidisciplinary collaboration.

PUBLICATIONS AND REFERENCES

The following publications of Energy Laboratory and related research were released during the past period or are cited as references in this issue. **MIT theses** may be ordered from the Library Document Services, MIT, Room 14-0551, Cambridge, MA 02139-4307. Other publications may be ordered from Energy Laboratory Publications, MIT, Room E40-473, Cambridge, MA 02139-4307, *only* if a price is assigned and *only* if prepaid by check payable to "MIT Energy Laboratory." Prices are postpaid surface mail. For air delivery, add 15% to US, Canada, and Mexico, and 30% elsewhere. A list of publications is available on request.

Publications marked by an asterisk (*) can be found or are forthcoming on-line via the following addresses:
Energy Laboratory:
http://web.mit.edu/energylab/www/publications.html
Center for Energy and Environmental Policy Research:
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Instructions for ordering paper copies of the reports and working papers are also available at the above listed sites or by telephoning 617-258-0307 for Energy Laboratory publications, 617-253-3551 for Center publications, and 617-253-7492 for Joint Program publications.

Reports and Working Papers

Babiker, M., and H. Jacoby. *Developing Country Effects of Kyoto-Type Emissions Restrictions.* Joint Program on the Science and Policy of Global Change Report No. 53. 16 pages. October 1999.*

Babiker, M., J. Reilly, and H. Jacoby. *The Kyoto Protocol and Developing Countries.* Joint Program on the Science and Policy of Global Change Report No. 56. 20 pages. October 1999.*

Bugnion, V. *Changes in Sea-Level Associated with Modifications of the Mass Balance of the Greenland and Antarctic Ice Sheets over the 21st Century.* Joint Program on the Science and Policy of Global Change Report No. 55. 28 pages. October 1999.*

Bugnion, V. *Model Estimates of the Mass Balance of the Greenland and Antarctic Ice Sheets.* Joint Program on the Science and Policy of Global Change Report No. 54. 34 pages. October 1999.*

Bugnion, V., and D. Reiner. *A Game of Climate Chicken: Can EPA Regulate Greenhouse Gases Before the US Senate Ratifies the Kyoto Protocol?* Joint Program on the Science and Policy of Global Change Report No. 57. 28 pages. November 1999.*

Joskow, P. *Comments in Response to FERC Rulemaking on Regional Transmission Organizations*. Center for Energy and Environmental Policy Research Working Paper No. MIT-CEEPR 99–010WP. 21 pages. October 1999.*

Robins, R., ed. *Symposium Summary, Proceedings of the 1999 Urban Air Toxics Summer Symposium.* Energy Laboratory Report No. MIT-EL 99–003. 30 pages. October 1999.* **(Ref. 1)**

Sem, T., and D. Ellerman. *North Sea Reserve Appreciation, Production and Depletion.* Center for Energy and Environmental Policy Research Working Paper No. MIT-CEEPR 99–011WP. 39 pages. October 1999.*

Wang, C., and R. Prinn. *Interactive Chemistry and Climate Models in Global Change Studies.* Joint Program on the Science and Policy of Global Change Report No. 52. 16 pages. September 1999.*

Other Publications

Allgor, R., and P. Barton. "Screening models for batch process development: Part II. Case studies." *Chemical Engineering Science*, v. 54, pp. 4065–4087, 1999.

Allgor, R., L. Evans, and P. Barton. "Screening models for batch process development: Part I. Design targets for reaction/distillation networks." *Chemical Engineering Science*, v. 54, pp. 4145–4164, 1999.

Awerbuch, S., L. Hyman, and A. Vesey, eds. *Unlocking the Benefits of Restructuring: A Blueprint for Transmission*. Vienna, Virginia: Public Utilities Reports, Inc., November 1999.

Barton, P., B. Ahmad, W. Cheong, and J. Tolsma. "Synthesis of batch processes with integrated solvent recovery." In *Tools and Methods for Pollution Prevention,* S. Sikdar and U. Diwekar, eds. Netherlands: Kluwer Academic Publishers, 1999.

Ellerman, A. "Obstacles to global CO_2 trading: A familiar problem." *Climate Change Policy*, pp. 119–132, May 1999.

Ilić, M., guest editor. *Journal of Discrete Event Dynamic Systems: Theory and Applications, Special Issue on Electric Power Systems*, v. 9, November 1999. Norwell, Massachusetts: Kluwer Academic Publishers, 1999.

Jacoby, H. "The uses and misuses of technology development as a component of climate policy." *Climate Change Policy*, pp. 151–169, May 1999.

Joskow, P. "Regulatory priorities for infrastructure sector reform in developing countries." In *Annual World Bank Conference on Development Economics 1998*. The International Bank for Reconstruction and Development: The World Bank, 1999.

Skolnikoff, E. "The role of science in policy: The climate change debate in the United States." *Environment*, v. 41, no. 5, p. 16, June 1999.

Wang, C., and R. Prinn. "Impact of emissions, chemistry and climate on atmospheric carbon monoxide: 100-yr predictions from a global chemistry-climate model." *Chemosphere: Global Change Science*, v. 1, pp. 73–81, 1999.

Wang, C.-C., and J. Ying. "Sol-gel synthesis and hydrothermal processing of anatase and rutile titania nanocrystals." *Chemical Materials*, v. 11, no. 11, pp. 3113–3120, 1999.

Weaver, J., T. Vaughan, and G. Martin. "Biological effects due to weak electric and magnetic fields: The temperature variation threshold." *Biophysical Journal*, v. 76, pp. 3026–3030, June 1999.

Ying, J. "Nanoporous systems and templates: The unique self-assembly and synthesis of nanostructures." *Science Spectra*, v. 18, pp. 56–63, 1999.

Yu, C., J. Leotard, and M. Ilić. "Dynamics of transmission provision in a competitive power industry." *Journal of Discrete Event Dynamic Systems: Theory and Applications, Special Issue on Electric Power Systems*, v. 9, pp. 351–390, November 1999.

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Room E40-479
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ISSN 0739-4233

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