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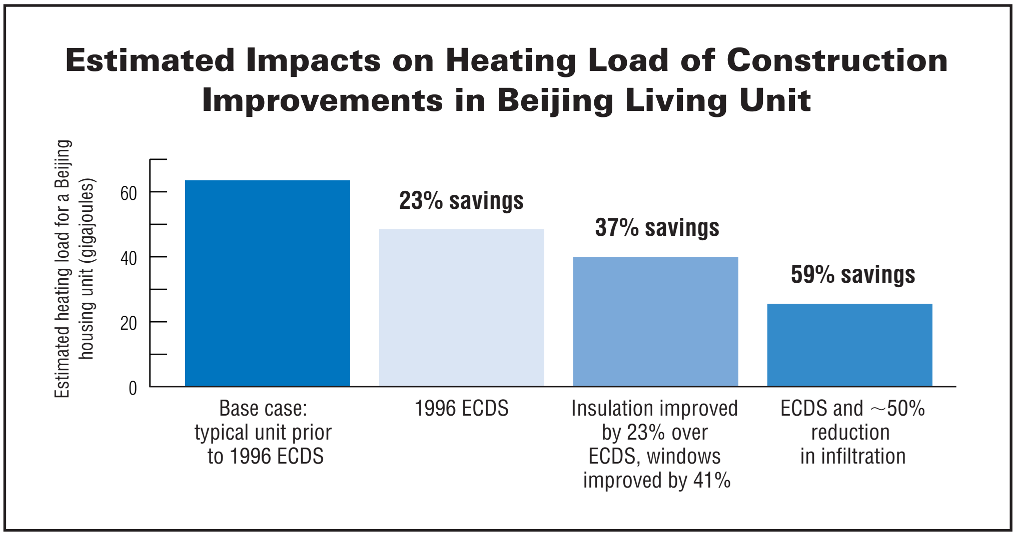
RESEARCH REPORTS

MIT LABORATORY FOR ENERGY AND THE ENVIRONMENT APRIL–JUNE 2002

China's New Residential Buildings: Saving Energy, Preserving Tradition

Inspired by a booming economy and new spending power, the people of China want the advantages that their Western counterparts have: more living space, more comfort, and more amenities. Studies by MIT researchers suggest that they can fulfill those dreams without necessarily adopting the energy-intensive practices of the West. For example, Chinese developers are now building some 10 million living units per year, most of them in high-rise structures that require extensive heating and cooling. Using numerical analysis and computer simulations, the MIT researchers demonstrated that the same living conditions could be provided using a group of low-rise buildings, designed and oriented to catch the sun's heat in winter and the prevailing winds in summer. In the new design, energy use is substantially lower, and people have access to outdoor communal areas traditionally valued by Chinese culture. Analyses of single living units showed that installing insulation and using better windows could reduce heating needs by 37%. Reducing air infiltration by tighter construction could push that total reduction up to 59%. Although Chinese leaders recognize the need for energy efficiency, various non-technical issues impede progress. Energy-efficient equipment is expensive; many construction workers are new to the trade and lack the skills to do high-quality work; China's building codes are not enforced through inspection of finished projects; and most consumers still get free heating so have little incentive to save energy. The MIT researchers are now helping Chinese policy makers develop "green guidelines"; they are continuing to work with developers on energy-efficient designs; and they are formulating simple computer-based tools that Chinese builders can use to compare the energy efficiency of design options.



The MIT research team modeled the energy consumption of a typical living unit in Beijing to estimate the impact on heating needs of several types of improvements. The first bar shows the base-case heating load, assuming a pre-1996 unit with no wall insulation and low-quality windows. The next three bars show savings from implementing China's 1996 Energy Conservation Design Standard (ECDS), from further improving insulation and windows, and finally from implementing the ECDS and also cutting air infiltration in half. Potential energy savings are significant, with the greatest incremental gain coming from tightening up construction to reduce air leaks.

During the past decade, rapid economic growth in China has significantly increased the standard of living for the nation's 1.3 billion inhabitants. Demand for more living space and greater comfort means that new construction is booming, air conditioners abound, demand for heating is rising, and more people are buying electric fans, washing machines, and refrigerators. Energy demand is certain to increase—a prospect that raises serious concern. In 1999, China consumed about 8% of the total energy used in the world, more than any nation except the United States. By 2020, China's total energy consumption could double, and—if China follows the historic trends of the Western world—residential and commercial building consumption could rise from its current small fraction to fully a third of the nation's total energy use. If coal continues to be the fuel of choice, China's energy use would substantially raise worldwide emissions of carbon dioxide.

Decisions made now in China's residential sector will clearly have a major impact on worldwide sustainability for decades to come. Recognizing the importance of "locking in" good practices for the long term, Leon R. Glicksman, Qingyan Chen, Leslie K. Norford, John Fernandez, Andrew M. Scott, and their colleagues in MIT's Building Technology Program have been working with Chinese collaborators to develop new sustainable buildings. For the past four years, they have been preparing conceptual designs and performing parallel technology studies for large-scale residential demonstration projects in Beijing, Shanghai, and Shenzhen (near Hong Kong). The cooperative effort involves MIT, Tsinghua University in Beijing, Tongji University in Shanghai, and local Chinese development companies. In two ongoing projects, the teams are designing a low-rise, high-density development for a 10-hectare site outside Beijing and a group of low-rise residential buildings for a 2-hectare site in Shenzhen (go to <http://chinahousing.mit.edu> for details on the Sustainable Housing in China Project).

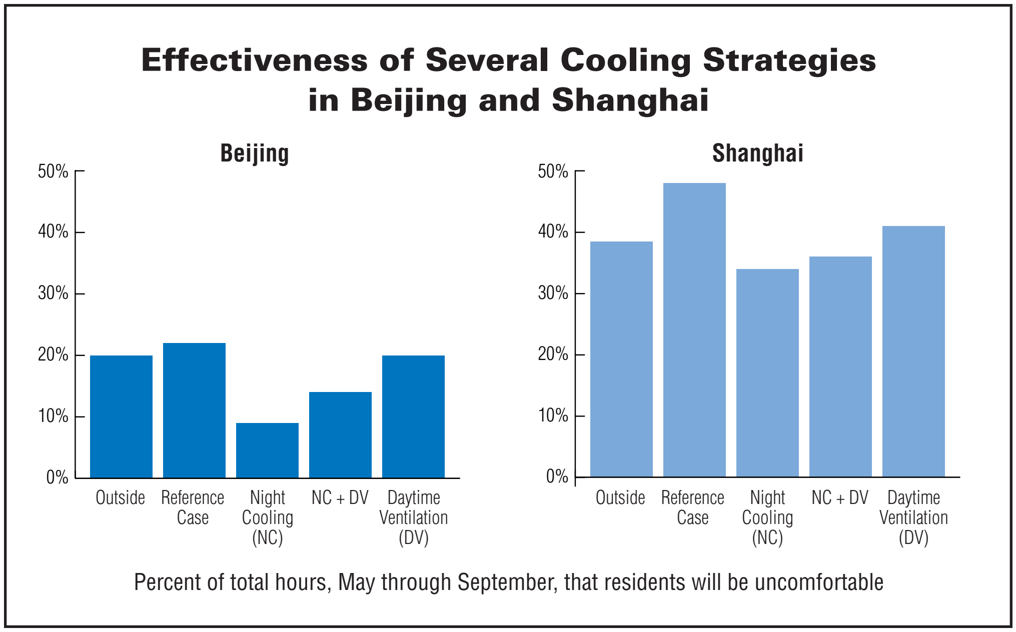
In working with the Chinese, the MIT researchers have made a troubling observation: developers are abandoning traditional Chinese practices and relying on energy-intensive Western methods instead. In the past, Chinese people typically lived in low buildings with communal green spaces. Designs were simple, were in harmony with nature, and made effective use of natural ventilation and solar heating. In contrast, the new buildings being put up by today's commercial firms are generally Western-style high-rise structures that isolate residents from one another and from outdoor spaces and depend on energy-consuming mechanical devices for heating and cooling.

In a series of recent studies, the MIT researchers showed that applying some of China's traditional approaches and other simple techniques to modern designs can yield substantial benefits. Their studies involved the use of advanced analytical techniques such as computational fluid dynamics (CFD) and dynamic heat-transfer modeling. But in each study they identified a design or approach that is straightforward to execute, saves energy, and helps to deliver the improved comfort levels that Chinese occupants now expect.

In one study, the researchers looked at strategies for reducing the need for heating, which now consumes more than 80% of the energy used in residential buildings. The figure on page 1 summarizes the strategies, their impacts on heating load, and the percent of energy savings they deliver. The first bar shows the base case—a typical pre-1996 Beijing home without wall insulation and with single-glazed, loose windows. The three bars to the right assume various improvements. The first shows the impact of implementing the current Chinese building code, the Energy Conservation Design Standard (ECDS) for New Heating Residential Buildings. The ECDS, adopted in 1996, is not as strict as American and Canadian codes are; but it does specify limits on heat transfer through windows, walls, and roofs. The next bar assumes further improvements in insulation and windows, and the final bar shows the result of meeting the ECDS and also cutting air infiltration in half through tighter construction. (Sufficient filtered fresh air is brought in to maintain indoor air quality.) Each change brings a substantial energy savings, with a maximum reduction of fully 59% compared to the base case. Reducing infiltration through good construction methods yields the greatest incremental savings—a result significant for policy makers, as the 1996 building code does not specifically address air infiltration levels.

Another analysis focused on strategies for cooling a typical housing unit in Beijing and in Shanghai. Among the options considered was a simple approach called night cooling. Occupants open windows at night, allowing the cool air to lower the temperature of concrete floors indoors. When day comes and the outdoor temperature rises, they close the windows, permitting the cool floors to keep the indoor temperature down.

As shown in the figure to the right, the researchers evaluated the strategies based on the percent of time residents without air conditioning will be uncomfortable during the cooling season (May through September). The left-hand chart shows results for Beijing. At the outside temperature, people will be uncomfortable about 20% of the time. The reference case assumes conditions inside the building, where



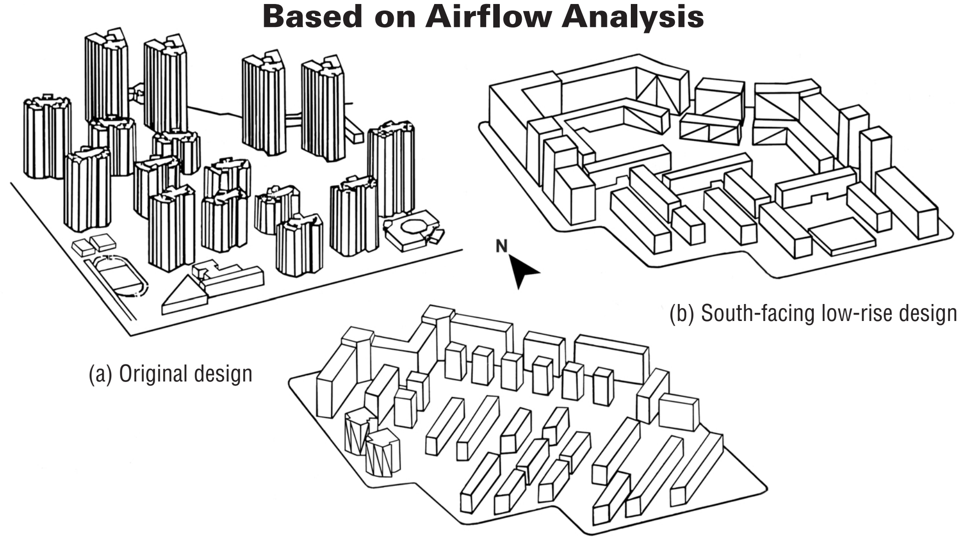
This figure shows the effectiveness of several cooling strategies, evaluated based on how much of the time residents will be uncomfortable during the cooling season (May through September) in a typical living unit in Beijing and in Shanghai. The "reference case" is indoors with no special ventilation strategy. "Night cooling" involves opening windows at night and shutting them during the day so cool building components such as concrete floors can keep the temperature down. "Daytime ventilation" calls for opening the windows just during the day. Night cooling is clearly an effective approach to reducing—or in Beijing even eliminating—the need for air conditioning.

heat from the sun leaves occupants uncomfortable slightly more of the time. Using night cooling leaves occupants uncomfortable only about 10% of the time. Combining night cooling with daytime ventilation—that is, leaving the windows open all the time—makes matters somewhat worse; and opening the windows only during the day is just as bad as being outside. Thus, in Beijing, night cooling is a highly effective, energy-free approach to cooling.

The right-hand chart shows results for Shanghai, a city far hotter and more humid than Beijing is. (In Shanghai, there are now about as many air conditioners as there are households.) Although the hours of discomfort are generally much greater, the results follow the same trends as in Beijing. Again, night cooling provides the most relief; but under the best conditions, occupants are still uncomfortable more than a third of the time. Thus, in Shanghai, night cooling can provide some energy-free comfort; but air conditioners are still needed as a supplementary source of cooling.

Those studies involve single units. But in many cases Chinese developers are planning whole communities on empty farmland. Rather than inserting a single building into a crowded neighborhood, they may need to build a series of buildings containing as many as 50,000 units—a situation that offers significant energy-saving opportunities. The MIT researchers used

Redesign of New Residential Community Based on Airflow Analysis



Airflow analysis is an effective technique for guiding the design of new communities in China. Scheme (a) is a design prepared by a Chinese architectural firm. Airflow analysis showed that scheme (b) could provide the same living space while better blocking winter winds and providing residents with greater access to outdoor spaces. In scheme (c), the buildings on the southern edge are rotated to enhance both passive solar heating in winter and cross ventilation from southerly winds in summer.

CFD analysis of airflows around structures to guide selection of the location and height of buildings for one such project.

Their results are shown in the figure to the left. The original design, prepared for the Chinese developer by an architectural firm, called for a group of widely spaced, tall towers. That approach fulfills the national requirement for each residential unit to receive at least one hour of direct sunlight in mid-winter. However, it does little to screen outdoor spaces from strong winter winds from the north. The second scheme, suggested by the researchers' airflow analyses, uses more numerous, low-rise buildings. This design provides just as much living space as the towers do but reduces winter winds among the buildings—and also provides occupants a closer connection with outside communal green spaces. However, further analysis showed that the north-south orientation of the buildings on the southern edge of the site is not favorable for either passive solar heating or cross ventilation from prevailing southerly winds in summer. In the third scheme, those buildings are rotated 45 degrees, giving a successful outcome under both winter and summer conditions.

While some of the changes identified in the MIT studies seem technically straightforward, several factors make them difficult to accomplish. Primary among those factors is the lack of enforcement of China's energy-conservation codes. Designs for buildings are submitted for approval, but the completed buildings are rarely inspected for compliance—and quality control is a serious problem. In China, many workers on new construction projects are former farmers with little or no experience in construction. Without proper training and skills, they cannot deliver the high-quality workmanship required to, say, install insulation properly or fit windows tightly.

A further source of poor quality is that—in the absence of inspection—Chinese builders may choose to cut costs, for example, by using inferior construction methods or materials that negate the design's intentions. They have two reasons to do so. First, good materials and components are expensive. Energy-efficient insulation, windows, and air-conditioning and heating equipment are typically provided by foreign-partnership enterprises and sold at prices too high for non-luxury housing.

The second reason is that today's consumers do not value energy efficiency. Their lack of interest was clearly demonstrated in a small-scale survey performed by MIT graduate student Lara Greden. Ms. Greden prepared a questionnaire that asked 36 prospective homebuyers in Beijing and 27 Chinese nationals in the United States to rate the most important characteristics of a home. Their top priorities were location, access to transportation, and quality of construction (a response to deaths and injuries resulting from construction flaws in buildings put up in the early 1990s). They were willing to pay no more than 10% of the base house price for a "green, sustainable, or energy-efficient" home.

Policy makers are now taking steps to encourage energy-efficient practices on both the construction and the consumer sides. One key policy question is how to increase demand for energy-efficient products manufactured in China. If that demand goes up, cost-cutting economies of scale can be realized, and products can be offered to developers at lower prices than are the imports that now dominate the market.

On the consumer side, one critical policy move is heating reform. In the past, China's district heating systems provided heat as a welfare good. Occupants of individual units did not pay for or control their own heat, so they had neither the incentive nor the ability to conserve. Chinese officials recognize that heat must become a marketed commodity to encourage conservation. Much discussion now focuses on the best technical approach to accomplish control and metering at the household level and on how to ensure that consumers, especially the poor, can afford the heat they need.

Another important need is to educate consumers. Just 20 years ago, housing was provided by the state. As a result, today's consumers—China's first generation of homebuyers—have much to learn about home ownership. One important lesson is how their construction decisions can affect their energy use. For example, many buyers of high-rise buildings increase their living space by closing in their outdoor balconies with permanent windows. But the enclosed balconies restrict airflow and trap incident solar radiation, increasing the need for air conditioning. In addition, many new homes are sold with unfinished interiors. While homeowners could install insulation, they typically choose not to. When they begin paying for their own heat, however, insulation will become a worthwhile investment. Homeowners in China will then need to evaluate the long-term savings they will get from their initial investment, and they will have to be able to afford making that investment—two factors that slow efficiency gains even in developed countries.

The MIT researchers are continuing to work closely with Chinese designers, developers, and policy makers to help foster energy-efficient buildings and practices. In addition to working on specific projects, they have held workshops in Beijing and Shenzhen at which they presented some of the principles of sustainable development and demonstrated that simple traditional Chinese design methods can contribute significantly to sustainability. They are also working with China's Ministry of Construction to develop and apply a set of sustainable green guidelines. They have begun to provide feedback on the ministry's preliminary design guidelines, and they have formulated a computer-based tool that Chinese developers can use to evaluate the sustainable features of their buildings. Rather than simply transferring Western technologies, the MIT researchers want to enable the Chinese to implement sustainable practices that draw on their own resources and capabilities and take into account the values and life styles of their own culture.

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Adopting Cleaner Technologies in the Mexican Auto Sector

Mexican policy makers face a dilemma: how can they get their automakers to promote the rapid adoption of cleaner automobile technologies, thereby reducing the main source of the severe air pollution in Mexico City? MIT research has shown that simply setting new auto emissions limits may not be sufficient, as many factors can hinder the effectiveness of such environmental policies. Conclusions come from case studies examining the adoption of three cleaner auto technologies during the past decade—catalytic converters, Tier 1 technologies, and on-board diagnostic systems. The research shows that environmental regulations such as stricter emissions limits could influence the timing of new technology adoption, for example, by including phase-in dates. But industry must also have the technical capability as well as incentives if such regulations are to be effective. Also required are infrastructures for cleaner fuel production and distribution and automobile maintenance facilities so that the new technologies perform effectively. Coordination among national, regional, and global auto sectors is also crucial. In 2000, Mexican automakers signed a 10-year agreement with the Mexican environmental authorities to adopt any new US or European automobile emissions standards, with a two-year delay. Ongoing scenario analysis of options aimed at reducing air pollution in Mexico suggests that Mexican environmental regulators should aggressively pursue policies supporting the deployment of cleaner auto technologies. The potential reductions in emissions are great; the costs would be borne by the polluters; and the strategies build on investments already made to provide such technologies to Mexico's neighbors to the north.

In Mexico City, air pollution is severe, persistent, and the source of serious health and economic consequences. Reducing emissions from passenger cars would dramatically reduce air pollution, but getting new and cleaner technologies into use poses added expense and manufacturing challenges for Mexican automakers. Despite those obstacles, some important new and cleaner auto technologies have been adopted during the past 10 years. However, there has been no comprehensive analysis of how those technologies actually came into use. Did new environmental policies adopted in Mexico make them happen? Did other factors encourage or support their adoption? Could something have been done to further expedite their introduction? Answering those questions will help policy makers in Mexico City and in other developing-world megacities make better decisions as they continue their quest for clean air.

For the past three years, Dr. Chizuru Aoki, under the supervision of Dr. Joanne M. Kauffman and Professors David H. Marks, John B. Heywood, and Mario J. Molina, has been investigating the forces at work in the implementation of clean auto technologies in Mexico. Her work is part of a large-scale program of collaborative research and integrated assessment intended to help Mexican decision makers identify effective strategies for improving air quality in the Mexico City Metropolitan Area (MCMA). Coordinated by Dr. Luisa T. Molina and Professor Molina, the "Integrated Program on Urban, Regional, and Global Air Pollution" brings together teams of researchers from MIT and Harvard University and collaborators from Mexico to develop a better scientific understanding of the air pollution in the MCMA and to clarify the broader social, economic, and technological dimensions of the problem. Among their tasks is exploring the possible costs and emissions impacts of taking certain actions, including policies that encourage the adoption of environmentally sound technologies.

Trying to understand how new technologies enter the marketplace is not a new idea. Much rigorous work has led to methodologies for identifying and analyzing the important factors and processes involved. But those studies have focused on "conventional" technological change, generally defined as change that helps generate wealth in the economy. Dr. Aoki is instead concerned with the adoption of technologies whose use improves the environment. Such "environmental technologies" may be helped or hindered by factors or processes not recognized by conventional analytical methodologies.

To identify important factors and processes —and to clarify the potential influence of environmental policies and institutions—Dr. Aoki examined the history of three successful emissions-related technologies: catalytic converters, Tier 1 technologies, and on-board diagnostic systems. All were adopted first in the United States and subsequently in Mexico. To put her case studies into context, Dr. Aoki performed a series of background analyses. She characterized air quality in the MCMA and the role played by auto emissions; she developed a general economic and industrial profile of Mexico, with emphasis on the structure and performance of the auto sector; she examined the institutions, laws, and other programs addressing air quality management; and she established a history of policies and standards controlling vehicle emissions.

To develop the case histories, she sent questionnaires to major automakers and interviewed about 50 representatives from industry, environmental and transportation agencies, and government agencies for economic and industrial development. Among the interviewees were individuals who were active in government and industry in the 1980s and 1990s. In addition, she performed an extensive review of the relevant literature. She thus established a picture of the environmental, political, and institutional history of the technology changes that had occurred. (The broader economic impacts, while important, were outside the scope of her research.)

Catalytic converters: Catalytic converters were adopted only after a long, sometimes antagonistic negotiation between the Mexican government and the auto sector. In the late 1980s, policy makers began discussing new emissions limits that could be met only by using catalytic converters. But industry objected, in part because of conflicts between existing industrial and economic policies and the environmental policy measure being proposed. The industry was subject to price and manufacturing controls and was therefore concerned about the increased costs of importing and installing catalytic converters. Various policy instruments intended to foster the development of domestic industry limited the use of imported materials and components needed to introduce catalytic converters. Nevertheless, Mexican-based auto manufacturers did not present a united front. Export-oriented firms did not raise strong opposition to the change. Because they exported their product, these manufacturers were allowed greater use of imported technologies, and they already had manufacturing experience with catalytic converters. Firms oriented toward the domestic market did not have those advantages and opposed the new limits. Further hindering the negotiation process was the political and institutional weakness of the environmental authorities relative to the economic and industrial authorities. Finally, the technology itself posed problems, as it required the use of unleaded gasoline. The state-run oil company PEMEX exported huge quantities of crude oil, but at that time it did not have the refining capacity to produce the volume of unleaded gasoline that would be needed.

Over time, the barriers to the adoption of catalytic converters eased. Companies were allowed to charge more for cars equipped with catalytic converters, and—in response to public concern about the health impacts of lead—PEMEX agreed to supply unleaded gasoline beginning in 1990. (In fact, PEMEX had to import the unleaded fuel, incurring expenses that initially offset about 10% of its revenues from selling crude.) Ultimately, more stringent standards were implemented in two steps, in 1991 and 1993. The 1991 interim standards were negotiated to allow some firms to catch up technologically before the final standards went into effect in 1993. Catalytic converters became standard equipment.

Tier 1: In 1999, Mexico introduced Tier 1 standards, still-stricter emissions limits that had been instituted by the US Environmental Protection Agency in 1994. Meeting the Tier 1 standards required an array of technologies including fuel injection and better catalytic converters. This time, the policy change went more smoothly. Mexico became a signatory of the North American Free Trade Agreement (NAFTA) in 1994, so price controls and export and import restrictions were phased out. The Mexican auto sector was more cohesive, and the higher number of exports to the north meant that many firms were already building Tier 1 vehicles for the US market. The technologies required were more accessible than catalytic converters had been, and they used gasoline that was already widely available in Mexico. Furthermore, environmental policy makers now had more political power and were able to offer incentives for making the change. Notably, new vehicles that met the Tier 1 standards would be exempt from driving restrictions placed on vehicles one day a week. They were also exempt from MCMA's time-consuming, twice-yearly inspection and maintenance (I&M) procedure for two years. Although the new standards were to become effective in 2001, many auto companies began manufacturing Tier 1 vehicles in 1999, in part because the exemptions from the driving restriction and the I&M requirement were such a big selling point with their customers.

On-board diagnostic (OBD) system: In November 2000, the auto sector signed a voluntary agreement to adopt several new technologies starting with their 2002 models. Primary among them was an OBD system that monitors various emission-related vehicle components and systems and, on sensing a malfunction, alerts the driver of the need for service or repair. New cars that meet the requirements will receive the two-year I&M exemption.

Unfortunately, several requirements of the new technologies have not yet been addressed. With the OBD system, reductions in emissions depend on the driver's taking action; but Mexico has not begun educating consumers about the role they must play. Moreover, repair shops and dealerships do not yet have the trained workers and equipment needed to identify the specific malfunction that may have prompted the alert. Finally, PEMEX was not part of the voluntary agreement so did not at that time commit to providing the low-sulfur fuel required for several of the new technologies. (PEMEX recently agreed to start providing the low-sulfur fuel.) On a positive note, in the voluntary agreement the auto sector made a 10-year commitment to adopt Tier 2 and any other advanced emission standards and technologies two years after they are introduced in the United States or Europe. Automakers are clearly hoping to replace policy uncertainty with a more predictable regulatory framework that ensures lead-time for accomplishing change.

The three case studies and the background analyses provide some useful insights into the process whereby air pollution mitigation technologies have been introduced into Mexico's auto sector. Dr. Aoki summarizes the important factors and their interrelationships in the conceptual model shown on page 10. The factors with numbers and bold titles are key building blocks for any type of technological change to occur. Legal and institutional frameworks—both domestic and external—must be put into place; automakers must develop the capability to manufacture or incorporate new technologies; and the new technologies must actually be implemented and brought into the marketplace.

The remaining factors are suggested by the three case studies. The relative importance of the factors and whether they encouraged or discouraged change differ in the three cases. In the early case study (the catalytic converter), technology adoption was largely influenced by the domestic factors, which appear at the right in the figure. Not surprisingly, domestic environmental policy was important; but its influence was overwhelmed by domestic industrial and economic policy (price controls, limits on imported technologies, and so on). Firm-to-firm differences and other characteristics of the domestic auto sector also played a major role. In the later case studies, the policy formulation strategy of Mexico had changed, and external factors gained importance. Domestic environmental policies and regulations were gradually replaced by policies set by outside players such as the United States. Characteristics of the global auto sector became increasingly important as the Mexican auto sector became more integrated into it. Finally, requirements of the technologies—the need for special fuel or for new repair and service capabilities—generally played a key role in their implementation.

Based on her studies, Dr. Aoki offers several lessons. From an academic perspective, her work demonstrates that the well-established concepts and theories of general technological change—developed during some 50 years of study—can provide a basic framework for assessing environmental technological change, a relatively new area of study. From a practical perspective, Dr. Aoki offers a series of lessons for policy makers in Mexico who are trying to achieve economic growth while protecting the environment—a challenge faced by leaders of many developing countries.

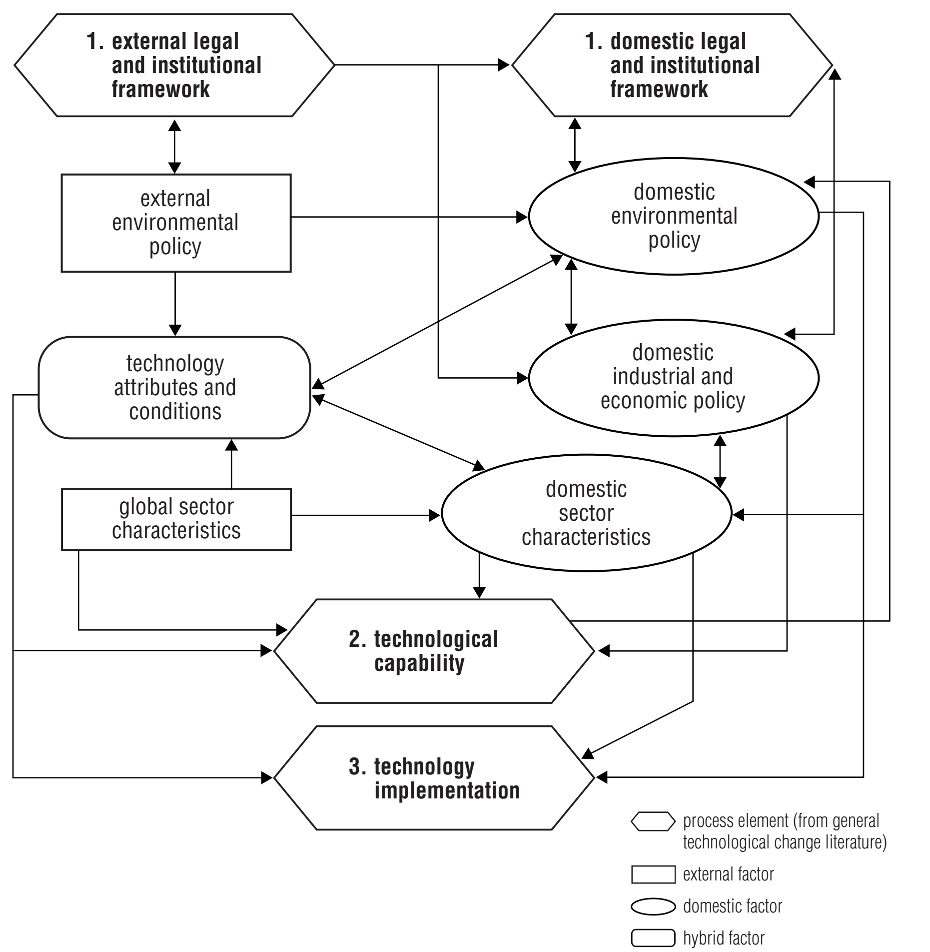
• Mexican authorities must be aware of both the capabilities and the limits of environmental policy. Environmental policy can influence the process of technological change by specifying the pace and timing of technology introduction (for example, by establishing a phase-in schedule for a particular technology), and it can provide incentives for change (for example, the driving-ban and I&M exemptions). But for change to occur, industry must develop the capability to manufacture cars with the new technology. That change will not happen unless industry has both incentives and the necessary technological ability. Thus, environmental policy alone cannot force industry to adopt, adapt, or create new technologies.

• Decision makers should guard against inconsistency and fragmentation in policy formulation. Environmental, industrial, economic, energy and fuel, and transportation policies should be coordinated to ensure that their objectives do not conflict. Mexican policy-making institutions must collaborate more closely than they have to date.

• Policy makers must be sure that the needs of any new technology are met. For example, if appropriate fuel supplies or necessary repair facilities are not in place, even the best technology innovation will not have any impact on actual emissions.

• If Mexican policy makers are going to rely on US and European environmental policy as their benchmark, they must watch out for shifts in the export markets served by Mexican automakers in the coming decades. As long as most of the exported cars are ending up in the

Conceptual Model of Environmental Technological Change



United States and Europe, reliance on US and European emission standards and policy making is warranted. But if export markets shift toward Latin America or the Caribbean, say, where emissions standards are less stringent, then reliance on the US and European "platform" is no longer valid, and policy makers may encounter resistance from the auto sector.

• During the next 10 years, when automakers are locked into US- and European-style emissions standards, authorities should expect to see opposition from the auto sector if they try to introduce Mexico-specific standards. In one recent example, the finance ministry proposed a new tax system in which vehicles with high emissions of nitrogen oxides (NO_X) would be taxed more than those with low NO_X emissions. (Scientific evidence shows that reducing NO_X emissions is likely to reduce ozone formation in the MCMA.) The tax system would take effect immediately, only within Mexico. Not surprisingly, the auto sector—having just made a 10-year agreement with the environmental authorities to follow the US and European lead—objected strenuously, and the proposal was dropped.

Dr. Aoki has now begun evaluating strategies for encouraging the introduction of cleaner auto technologies along with other options for mitigating air pollution. To assess the effectiveness of the vehicle-oriented options, Dr. Aoki has been performing a quantitative scenario analysis of the impacts of policies affecting emission-control technologies, fuel economy, fuel quality, driving habits, and other factors. Her analysis considers the next 25 years and various assumptions for parameters such as economic and population growth. She projects how much each policy would cost, who would pay, the embodied emission-reduction potential, and the feasibility of implementing the policy. (Other researchers on the Mexico City project are evaluating the environmental and public health benefits that would result.)

Initial results from the analysis confirm the attractiveness of policies focusing on the automobile sector. Automobiles are a major source of MCMA's air pollution, so the potential benefits from controlling their emissions are great. Moreover, the cost is not distributed over the entire population but instead borne by those who can most afford it. Auto ownership is usually influenced largely by per capita income and income growth. Projections suggest that, even under optimistic scenarios of income growth, fewer than 30% of the people in the MCMA will own cars by 2025. Having the cost of the emissions reduction borne by the upper 30% bracket of the income distribution would minimize concerns over equity, fairness, and distributional impacts. Finally, automobile-oriented policies are attractive because the auto sector and environmental policy makers have over time learned to work together to find approaches and solutions that are mutually agreeable or even beneficial. However, one concern remains: while the adoption of advanced auto technologies may make the air cleaner, it will not reduce the severe traffic congestion in the MCMA. Another challenge is therefore to find ways of encouraging the adoption of advanced technologies in public transportation systems so as to improve their performance enough to lure drivers out of their cars.

Chizuru Aoki received her PhD in Technology, Management, and Policy at MIT in June 2002. Joanne M. Kauffman is a principal research scientist in the Laboratory for Energy and the Environment. David H. Marks is the Morton '42 and Claire Goulder Family Professor of Engineering Systems and Civil and Environmental Engineering and director of the Laboratory for Energy and the Environment. John B. Heywood is the Sun Jae Professor of Mechanical Engineering and director of the Sloan Automotive Laboratory. Mario J. Molina is an Institute Professor. Luisa T. Molina is the executive director of the Integrated Program on Urban, Regional, and Global Air Pollution. *This research was supported by the Integrated Program on Urban, Regional, and Global Air Pollution with funds provided by the Fideicomiso Ambiental del Valle de México, the MIT Alliance for Global Sustainability, and the National Science Foundation. Further information can be found in reference 2.*

News Items

On May 2–3, the **Center for Energy and Environmental Policy Research** held its **spring workshop**. Topics included retail electricity and natural gas markets, banking behavior in the sulfur dioxide allowance market, the cost of scrubbing "the rest of the coal," the Enron aftermath, US oil and natural gas production, and implications of the Argentine default. Guest speakers were David L. O'Connor, Commissioner of the Massachusetts Division of Energy Research, whose talk was entitled "Restructuring Electricity Markets in New England: Current Challenges and Future Prospects"; and Professor Ronald G. Prinn, co-director of MIT's Joint Program on the Science and Policy of Global Change, who addressed the question: Is the cleansing capacity of the atmosphere changing? The workshop drew more than 40 participants from industry, government, and academia.

The **Joint Program on the Science and Policy of Global Change** held **Global Change Forum XIX** in Paris on June 12–14 in collaboration with the Centre Internationale de Recherche sur l'Environnement et le Développement. The theme of the forum was "**Managing Fragmented Climate Regimes**." Topics included the evolving state of the climate regime, emerging trading systems, trade balance and competitiveness issues, the role of regional climate forecasts in policy, linkages between climate and air pollution, and forces pushing for convergence. The keynote address was delivered by Professor Gérard Mégie, president of the Centre National de la Recherche Scientifique. Meeting participants included about 115 representatives of industry, government, international organizations, and research groups.

On May 3rd, the **MIT Technology and Policy Program** held an all-day, in-depth conference entitled "**Sustainable Mobility: Global Challenges for the 21st Century**." The symposium highlighted the report ***Mobility 2001***, which was commissioned in late fall, 2000, by the World Business Council for Sustainable Development (WBCSD) and prepared by researchers from MIT and Charles River Associates. The six-month, million-dollar study involved a comprehensive, systematic assessment of mobility conditions and challenges worldwide at the end of the 20th century—the first step toward identifying strategies for achieving sustainable mobility by 2030. (The findings of *Mobility 2001* were summarized in *e-lab*, January–March 2002. The full report is available on the Web at <http://lfee.mit.edu/publications/>.) At the symposium, speakers addressed the "grand challenges" identified in the report, offering a public platform for discussion of its findings. Included in the international audience of more than 200 people were policy makers, government officials, industry leaders, researchers, and others. Sessions focused on urban mobility in developed countries, urban mobility in developing countries, and regional and intercity passenger and freight transportation.

The 21 speakers included MIT researchers, transportation consultants from the United States and the United Kingdom, the former mayor of Bogotá, Colombia, and industry and WBCSD executives. The keynote speaker was Lawrence Burns, vice president for research and development at General Motors, who emphasized that achieving sustainability will require collaboration among governments, companies, and countries—and likely a move toward a hydrogen economy. Accordingly, later this year GM plans to release a prototype auto powered by a hydrogen fuel cell system rather than an internal combustion engine. Other important themes at the symposium were the role and impact of emerging technologies on transportation issues and planning, new issues of security, and especially the mobility challenges for developing countries. Enrique Penalosa, former mayor of Bogotá, noted that the challenge for developing countries is not just controlling pollution—relatively few people have cars—but also providing mobility systems that are economically viable, socially equitable, and sustainable. Successful projects in his city have focused on development of a new, bus-based transit system with dedicated bus lanes as well as construction of hundreds of miles of sidewalks, bike paths, and pedestrian streets.

Consensus at the symposium was that sustainable mobility may be viable but will take enormous effort and will be achievable only through interdisciplinary and collaborative work to improve transportation and infrastructure technologies and to identify and implement effective policy actions. Of primary importance is finding ways to reduce the growing dependence on automobiles and fossil fuels and to foster effective mass transportation and other mobility options that will improve the quality of life of the many people worldwide for whom personal car ownership is not an option.

The symposium was cosponsored by the MIT Engineering Systems Division, the Laboratory for Energy and the Environment, the US Department of Transportation, and the WBCSD.

Publications and References

The following publications covering Laboratory for Energy and the Environment (LFEE) and related research became available during the past period or are cited as references in this issue. Center for Advanced Nuclear Energy Systems (CANES) reports are available from Michael Messina, MIT Department of Nuclear Engineering, Room 24-207A, Cambridge, MA 02139-4307 (tel.: 617-253-3808). MIT theses may be ordered from the Libraries Document Services, MIT, Room 14-0551, Cambridge, MA 02139-4307. Other publications may be ordered from LFEE Publications, MIT, Room E40-473, Cambridge, MA 02139-4307, only if a price is assigned and only if prepaid by check payable to "MIT Laboratory for Energy and the Environment." 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:

Laboratory for Energy and the Environment:
http://lfee.mit.edu

Center for Energy and Environmental Policy Research:
http://web.mit.edu/ceepr/www/

Joint Program on the Science and Policy of Global Change:
http://web.mit.edu/globalchange/www/

Instructions for ordering paper copies of the reports and working papers are also available at the sites listed above or by telephoning 617-258-0307 for LFEE publications, 617-253-3551 for Center publications, and 617-253-7492 for Joint Program publications.

Reports and Working Papers

Babiker, M., G. Metcalf, and J. Reilly. *Tax Distortions and Global Climate Policy.* Joint Program on the Science and Policy of Global Change Report No. 85. 26 pages. May 2002.*

Gupta, S. *Incentive-based Approaches for Mitigating Greenhouse Gas Emissions: Issues and Prospects for India.* Joint Program on the Science and Policy of Global Change Report No. 86. 30 pages. June 2002.*

Yuan, Y., H. No, and M. Kazimi. *Nuclear Fuel Cycle Technology and Policy Program.* CANES Report No. MIT-NFC-TR-037. 78 pages. December 2001.

Other Publications

Adelman, M. "World oil production & prices 1947–2000." *Quarterly Review of Economics and Finance*, v. 42, pp. 169–191, 2002.

Aoki, C. *Technological Change for Environmental Improvement: The Case of the Mexican Automobile Sector.* PhD thesis. MIT Engineering Systems Division. June 2002.
(Ref. 2)

Bryden, K., and J. Ying. "Nanostructured palladium-iron membranes for hydrogen separation and membrane hydrogenation reactions." *Journal of Membrane Science*, v. 203, pp. 29–42, 2002.

Ellerman, A. "Designing a tradable permit system to control SO_2 emissions in China: principles and practice." *Energy Journal*, v. 23, no. 2, pp. 1–26, 2002.

Glicksman, L., L. Norford, and L. Greden. "Energy conservation in Chinese residential buildings: progress and opportunities in design and policy." *Annual Review of Energy and the Environment*, v. 26, pp. 83–115, 2001. **(Ref. 1)**

Montero, J.-P. "Multipollutant markets." *RAND Journal of Economics*, v. 32, no. 4, pp. 762–774, Winter 2001.

Papaefthymiou, G., K. Bryden, and J. Ying. "Mossbauer spectral characteristics of nano-structured Pd-Fe films." *Physica B*, v. 311, pp. 279–284, 2002.

Shwageraus, E., X. Zhao, M. Driscoll, P. Hejzlar, and M. Kazimi. *Micro-Heterogeneous UO_2-ThO_2 Fuel Designs Evaluation.* Presented at American Nuclear Society International Conference on Advanced Power Plant Technology, June 2002. 10 pages. $10.00

NEW AND RENEWED PROJECTS, APRIL–JUNE 2002

Topic	Donor or Sponsor	Investigators *(Department)*
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Piston Ring Packing Analysis for High Performance Engines	Ferrari SpA	John Heywood *(Mechanical Engineering)*
Assess and Document IGCC/Carbon Sequestration Environment Characteristics and Economics	Clean Air Task Force	H. Herzog *(Laboratory for Energy and the Environment)*
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Multidisciplinary Research on Energy Efficient Low Pollution Technologies in China		K. Polenske *(Urban Studies and Planning)*
New Technologies for Assessing the Sustainability of Agriculture in Developing Countries		D. McLaughlin *(Civil and Environmental Engineering)*
Climate Modeling at AGS		P. Stone *(Earth, Atmospheric, and Planetary Sciences)*
The Value of Knowledge		J. Kauffman *(Laboratory for Energy and the Environment)*

Stafford, D., K. Yanagimachi, P. Lessard, S. Rijhwani, A. Sinskey, and G. Stephanopoulos. "Optimizing bioconversion pathways through systems analysis and metabolic engineering." *PNAS* (Proceedings of the National Academy of Science), v. 99, no. 4, pp. 1801–1806, February 19, 2002.

Wong, M., H. Huang, and J. Ying. "Supramolecular-templated synthesis of nanopourous zirconia-silica catalysts." *Chemical Materials*, v. 14, no. 5, pp. 1961–1973, 2002.

Xu, Z., M. Driscoll, and M. Kazimi. "Neutron spectrum effects on burnup, reactivity, and isotopics in UO_2/H_2O lattices." *Nuclear Science and Engineering*, v. 141, pp. 175–189, 2002.

York, G., J. Stubbe, and A. Sinskey. "The Ralstonia eutropha PhaR protein couples synthesis of the PhaP phasin to the presence of polyhydroxybutyrate in cells and promotes polyhydroxybutyrate production." *Journal of Bacteriology*, v. 184, no. 1, pp. 59–66, January 2002.

NEW AND RENEWED PROJECTS, CONTINUED

Topic	Donor or Sponsor	Investigators *(Department)*
MIT AGS, continued	AGS	
Tools for Integrated Decision Making in the Chemical Industry		G. McRae *(Chemical Engineering)*
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Role of Innovative Technology for Promoting Sustainable Mobility		J. Heywood *(Mechanical Engineering)*
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ISSN 0739-4233

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