Summer 2009

ENERGY EFFICIENCY

The BRIDGE

LINKING ENGINEERING AND SOCIETY

The Potential of Energy Efficiency: An Overview
Lester B. Lave

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The
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The BRIDGE

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LINKING ENGINEERING AND SOCIETY

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Editor's Note

Maxine Savitz

Expanding Opportunities for Energy Efficiency

The United States, the world's largest consumer of energy, is responsible for about 20 percent of energy consumption worldwide. China, its closest competitor, consumes about 15 percent. In the past two years, the complex subject of energy and climate change, national security, and long-term U.S. economic vitality has been pushed to the forefront of national debate.

In the spring 2009 issue of *The Bridge*, I wrote a status report of the National Academies ongoing study, *America's Energy Future: Technology Opportunities, Risks and Tradeoffs* (AEF). The purpose of the AEF study is to inform the national dialogue on energy by providing authoritative estimates of current energy use and potential improvements with existing and new energy demand and supply technologies, their associated impacts, and projected costs. These estimates will help policy makers focus on the most promising options for our energy future.

The AEF study and other recent studies (APS, 2008; Creyts et al., 2007; Interlaboratory Working Group, 2000; NRC, 2008) have concluded that the most cost-effective near-term option is to deploy existing energy-efficient technologies, particularly in the next decade. Potential energy savings from available technologies in buildings, industry, and transportation could more than offset projected increases in U.S. energy consumption through 2030.

Improving energy efficiency in this way would mean the United States would consume about the same amount of total energy in 2030 that it consumes today, despite an increase in population and GDP. Reducing energy demand through energy efficiency will also reduce greenhouse gas (GHG) emissions and U.S. dependence on foreign oil. Currently available, cost-effective, energy-efficient technologies can improve efficiencies in lighting, heating, cooling, refrigeration, transportation, and other areas throughout our economy. Hundreds of realistic, demonstrated technologies are already commercially available. Others are just beginning to enter the marketplace.

You will note that the term "energy efficiency," rather than "energy conservation," is used throughout this edition of *The Bridge*. Energy efficiency is defined as the achievement of at least the same output of goods and services (at the same or lower cost) while using less energy. Energy conservation, which can include measures such as lowering the thermostat in winter, is an important strategy for reducing energy use, but it usually does not involve a change or improvement in technology.

No matter what form a more efficient product or piece of equipment or process takes and no matter which system is used to measure it, the goal is always to provide the same or higher level of service to the consumer while reducing the amount of energy used. Examples are vehicles that get more miles per gallon; production processes that yield more tons of steel per British thermal unit (BTU) of energy; and lighting that provides more lumens per watt.

In this edition of *The Bridge*, articles address energy-efficiency opportunities in all sectors of the economy, from a case study of efficient energy use in New York City to measures taken in China to implement energy-efficient technologies. Lester Lave's introductory article provides an overview of the potential of energy-efficient technologies in buildings, industry, and transportation. The three papers that follow describe examples from each of these economic sectors.

Jeremy Patt and **William Banholzer** of Dow Chemical Company describe how the chemical industry is using energy more efficiently through improvements in existing processes, the commercialization of new processes, the recovery of waste, and the creation of products for buildings and transportation that will enable energy savings. Dan Sperling and Nic Lutsey describe how existing and developing technologies can reduce energy use and GHG emissions in the transportation sector. Robin Roy and Brandon Tinianov describe new energy-efficient windows that can reduce heating and cooling costs by as much as 50 percent. They also discuss the importance of retrofitting existing residential buildings and explain how this relates to the current federal economic stimulus initiative.

In the past 30 years, several states have taken the lead in promulgating aggressive policies for improving energy efficiency. Paul DeCotis describes how New York state has kept electricity use per capita nearly constant for two decades, resulting in a use per capita rate 40 percent below the national average.

Energy use in China, the second largest consumer of energy in the world, has increased rapidly in the past decade. In their article, Mark Levine, Nan Zhou, and Lynn Price explain that industrialization in developing countries means a concomitant increase in energy use and GDP. In China, however, although GDP more than quadrupled from 1980 to 2000, energy consumption was not even doubled.

All of the articles explain how technologies that exist today, or are about to emerge, can yield energy savings. Technologies that should be available in the next 10 years include solid-state lighting, advanced cooling systems, integrated designs, advanced materials, improved sensors and controls, and improved batteries and fuel cells that could enable the large-scale deployment of plug-in hybrid vehicles and hydrogen fuel-cell vehicles.

The United States has many options for cost-effective measures for increasing efficiency in energy use (the most practical way to reduce energy demand), reduce GHG emissions, and increase our energy security in the near future. Improving energy efficiency is essential to ensuring that enough energy will be available for decades to come. We must and can make changes now, and we must do so in a way that leads to sustained, continuous improvements in the way we use energy in the future.

Maxine Savitz

References

APS (American Physical Society). 2008. Energy = Future: Think Efficiency. Available online at *http://www.aps.org/energyefficiencyreport/index.cfm*.

Creyts, J., A. Derkach, S. Nyquist, K. Ostrowski, and J. Stephenson. 2007. Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost? U.S. Greenhouse Gas Abatement Mapping Initiative Executive Report. December 2007. McKinsey & Company. Available online at *http://www.mckinsey.com/clientservice/ccsi/pdf/US_ghg_final_report.pdf*.

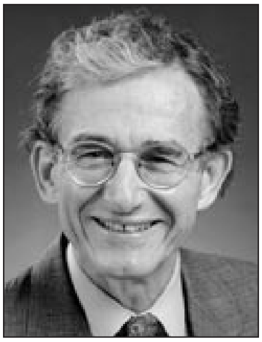
Interlaboratory Working Group. 2000. Scenarios for a Clean Energy Future. ORNL/CON-476 and LBNL-44029. November. Oak Ridge National Laboratory, Oak Ridge, Tennessee, and Lawrence Berkeley National Laboratory, Berkeley, California.

NRC (National Research Council). 2008. The National Academies Summit on America's Energy Future: Summary of a Meeting. Washington, D.C.: National Academies Press.

Overcoming formidable barriers to energy efficiency will require public and private support.

The Potential of Energy Efficiency

An Overview



Lester B. Lave is Harry B. and James H. Higgins Professor of Economics and University Professor, Carnegie Mellon University, and a member of the Institute of Medicine.

Lester B. Lave

Efficient technology that requires less energy than is currently used to get the same or better output has fueled the growth of our economy for more than a century. But while America was building its infrastructure and developing its industry and service sectors, the energy intensity of the economy, BTU per dollar of output, fell dramatically. If this had not happened, it would now take four times as much petroleum, coal, and natural gas to produce current GDP, at the 1919 energy-intensity level. This would amount to 85 percent of the current world production of fossil fuels—just to support the U.S. economy. Producing, transporting, and using that much energy, even if it were technically feasible, would devastate the natural environment and contribute to carbon dioxide emissions that would exceed the atmospheric concentration some scientists think would be catastrophic.

Figure 1 suggests the potential for improving energy efficiency to reduce our consumption and emissions. U.S. energy intensity dropped by half from 1919 to 1973 and then dropped by half again from 1973 to 2006, rates of 1.6 percent and 2.1 percent per year, respectively. Thus energy intensity decreased in the last three decades almost twice as fast as during the previous five decades. Since GDP is projected to grow at 2.5 percent per year through 2030, unless we continue to lower our energy intensity, the United States will use 69 percent more energy in 21 years than it uses today. That would require more than doubling our imports of oil and vastly increasing our imports of natural gas.

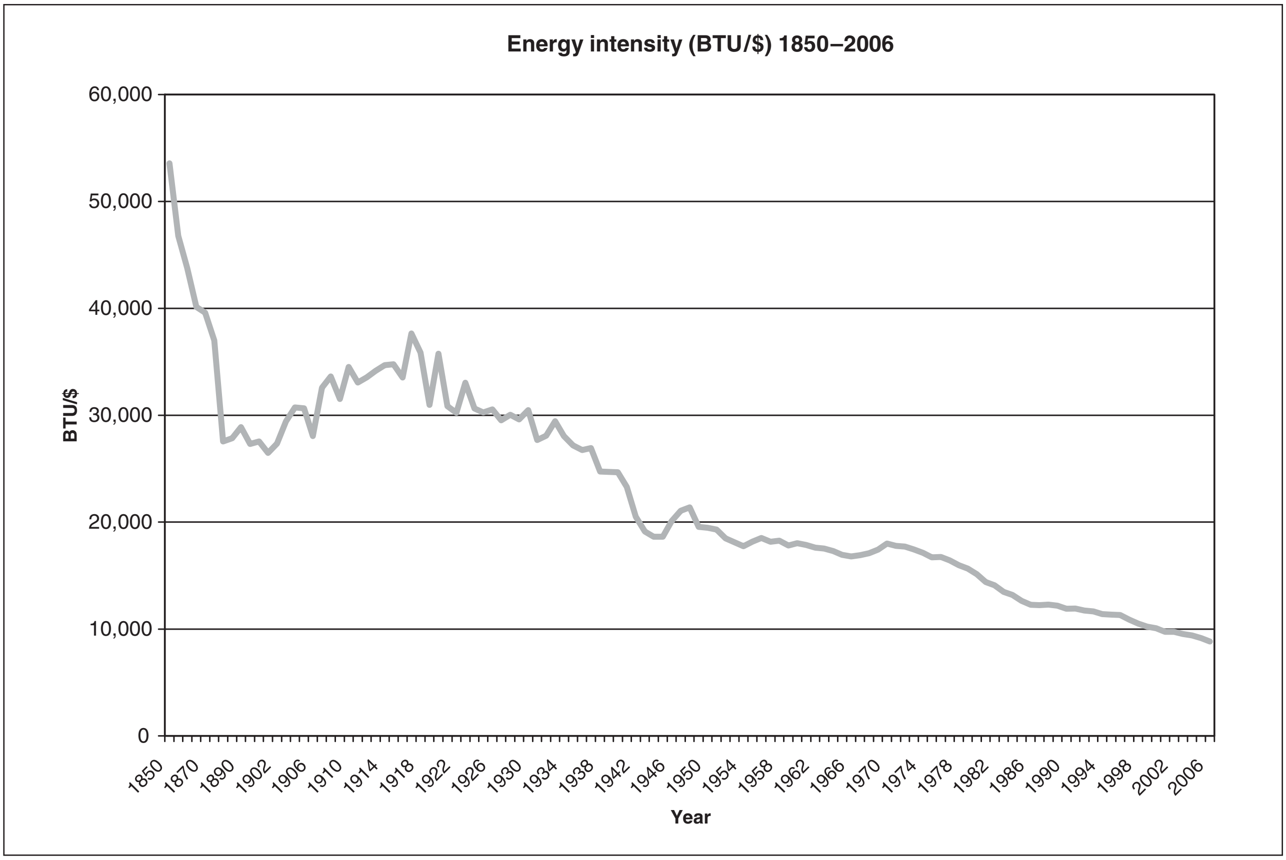


FIGURE 1 U.S. energy use per dollar of GDP, 1850–2006. Sources: based on EIA, 2008b; Schurr and Netschert, 1960.

If energy intensity continues to drop at an annual rate of 2.1 percent, as it did from 1973 to 2006, total energy use in the economy would rise by only 8 percent by 2030, putting less pressure on our imports and the environment. If we could find a way to reduce energy intensity even more, to 2.5 percent per year instead of 2.1 percent, we could keep energy use from growing, despite a growing economy. This would have enormous benefits for environmental quality (including reducing greenhouse gas emissions), energy security, and our balance of payments. However, this decrease is not likely unless policies are adopted that motivate investments in energy efficiency.

The potential for realistic conservation, as well as for greater energy efficiency, is suggested by comparisons of energy intensity in the United States and energy intensity in other advanced nations. Table 1 shows energy use per capita and per dollar of GDP for the United States, Japan, Denmark, France, and Germany. Japan and Denmark use about half the energy per capita, and France and Germany use a bit more than half of the per capita energy used in this country. In Japan and Denmark, energy use per dollar of GDP is half the U.S. level, and in France and Germany, it is about three-quarters of the U.S. level. An analysis by the International Energy Agency concludes that about half the difference between the United States and Europe is attributable to energy efficiency and about half to other factors, such as life style (IEA, 2004).

TABLE 1 Energy Use in 2005—Per Capita and Per Dollar of GDP

	BTU per person (million BTUs)	BTU per dollar of GDP
United States	340	9,113
Japan	177	4,519
Denmark	153	4,845
France	182	7,994
Germany	176	7,396

Source: EIA, 2009b,c.

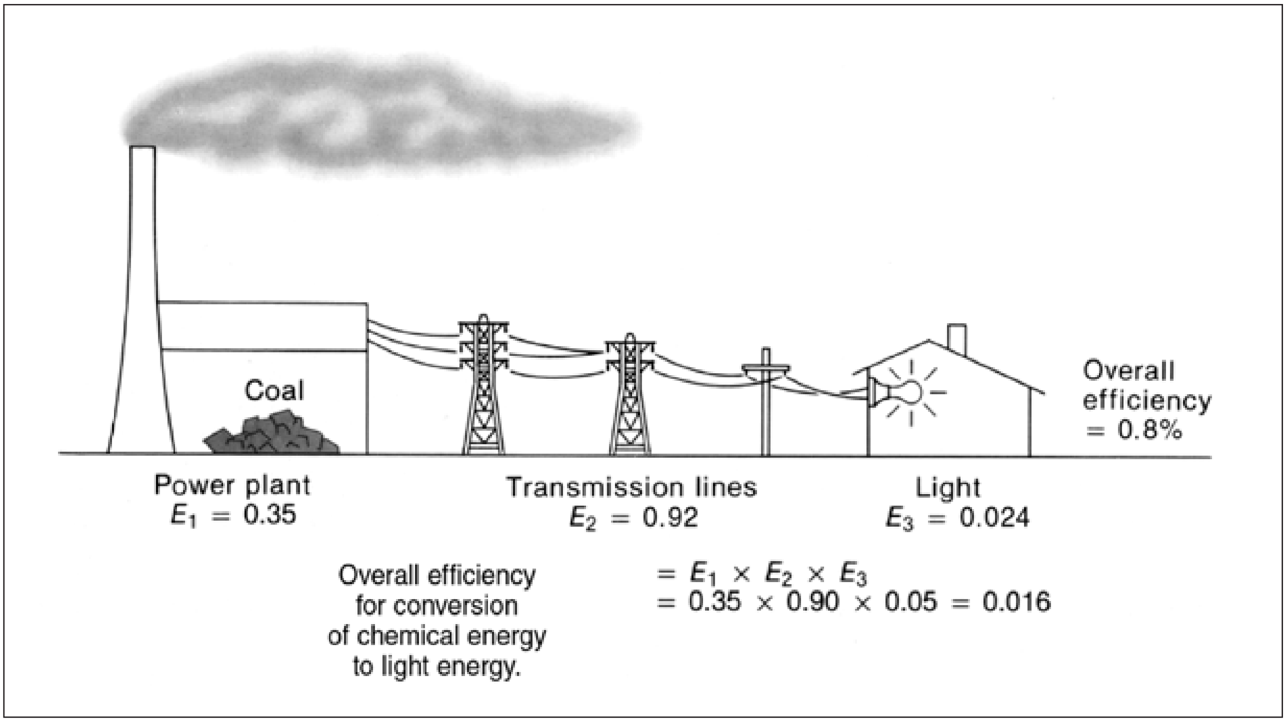


FIGURE 2 Lighting efficiency. Source: NRC, 2009.

Japan, France, and Germany are highly industrialized nations, and Denmark, France, and Germany have income levels comparable to ours. To be sure, this sort of aggregate comparison does not account for the GDP mix, climate, size, or passenger and freight transport for each nation. Nevertheless, the comparisons suggest that Americans might be able to cut energy use per capita by almost half if we were to adopt a European life style and European levels of energy efficiency.

In *Real Prospects for Energy Efficiency in the United States*, published as part of a National Academies project called America's Energy Future, a panel of experts evaluates the prospects for energy efficiency through the first half of this century, with a focus on the next decade. The panel details efficiency increases that could be achieved by making buildings, transportation, and industry more energy efficient and concludes that, compared to current projections of energy use in 2020 and 2030, additional energy savings of 30 percent are possible by 2030. About half of those savings could be realized in the next decade. In terms of cost, the panel concludes that saving energy would be far less expensive than buying additional energy at mid-2008 prices (NRC, 2009).

Examples of improvements in energy efficiency are plentiful. Figure 2 shows that burning coal to produce electricity to generate light is perhaps 0.8 percent efficient. A modern compact fluorescent lamp (CFL) is roughly four times as efficient as an incandescent lamp. The *New York Times* reports that manufacturers are displaying light-emitting diodes (LEDs) that are 10 times as efficient as an incandescent lamp (Taub, 2009). Another example, shown in Figure 3, is the annual energy use of a refrigerator. Compared to a 1974 model, a new refrigerator, which is both larger and cheaper, would use only 31 percent as much electricity.

The point is that, measured at the aggregate level, whether we look at energy use in the United States over time or compare it to energy use in other nations, or at the process level (e.g., lighting, refrigerators, other appliances), tremendous progress in energy efficiency has been made, and there is a huge potential for more progress in the future.

In the remainder of this article, I describe energy efficiency in buildings, the industrial sector, and, briefly, the transportation sector.[1] I then identify barriers to implementing energy-efficient technologies and the drivers of energy efficiency.

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[1] Energy efficiency in light-duty vehicles is explored in the article on p.22 by Dan Sperling, a member of the Energy Efficiency Panel, and Nic Lutsey.

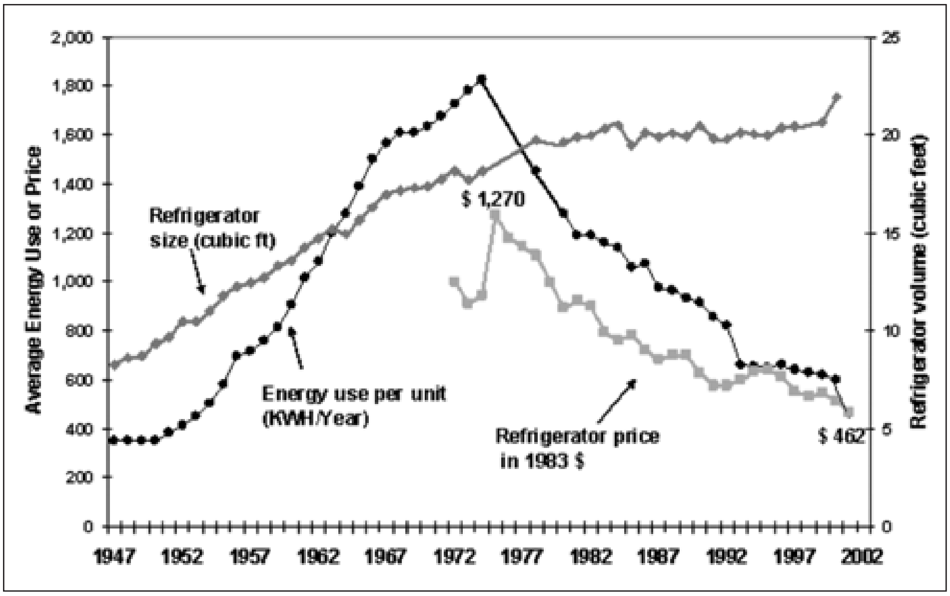


FIGURE 3 Efficiency of refrigerators. Source: NRC, 2009.

Energy Use in Buildings

The 81 million single-family houses, 25 million multifamily residences, and 7 million mobile homes, together with 75 billion square feet of commercial floor space account for 73 percent of electricity use and 40 percent of total energy use in the United States. From 1975 to 2005, despite increased energy efficiencies, an increase in the number of residences and the amount of commercial space led to substantial increases in total energy use—15 percent in residential buildings and 50 percent in commercial buildings.

The efficiency gains, which were made in refrigerators and lighting, as well as in air conditioners, building envelopes, and many appliances, were promoted by Energy Star labeling of appliances and even of buildings. For example, the number of new residences that attained Energy Star status increased from 57,000 in 2001 to 189,000 in 2006. For buildings, the median cost-effective and achievable potential (taking barriers to implementation into account) are 24 percent for electricity and 9 percent for natural gas. Unfortunately, this potential is sensitive to price, especially for natural gas.

Although potential gains from individual projects (e.g., appliances) are significant, the gains would be much greater if an integrated whole-building approach were adopted. Buildings can achieve much more substantial savings if they are designed to take advantage of natural light and if equipment is placed to reduce heating and cooling energy. A small but growing number of buildings have achieved a 50 percent savings in the energy used for heating, cooling, and hot water. Energy use for some buildings can be reduced by putting solar photovoltaic cells on the roof, which can transform a building into a net energy generator, although this is unlikely to be cost effective.

One way to view possible energy savings in buildings is to use "conservation supply curves" that estimate the cost of the energy conserved by using energy-efficient appliances or by renovating a structure. However, because conservation supply curves do not use an integrated approach, they are likely to understate the amount of efficiency that is cost effective. For example, switching from incandescent lamps to CFLs not only reduces energy use for lighting, but also reduces the air conditioning load in commercial buildings, allowing for downsizing of equipment and reducing the amount of energy required to cool the building. All of these technologies are generally available in the marketplace and are well proven.

Figure 4 is a representative conservation supply curve for residences. The figure shows how much electricity can be saved for all U.S. residences with various expenditures, beginning with the most cost-effective changes. For example, if all consumers selected energy-efficient color televisions rather than standard ones, they would save a total of 70 TWh of electricity per year at a cost of 1 cent per kWh, a 90 percent reduction in operating cost. Energy-efficient lighting, such as CFLs, could save an additional 160 TWh at a cost of just over 1 cent per kWh. In total, choosing the 12 appliances listed in Figure 4 rather than their less efficient models could save more than 600 TWh per year (about 15 percent of total electricity use) at a cost of 8 cents per kWh or less, leading to substantial dollar savings as well as substantial energy savings.

Unfortunately, realizing these energy and dollar savings will take many years. The analysis assumes that the purchaser chooses the more efficient alternative over the less efficient alternative when it is time to buy a new appliance. However, because furnaces and air conditioners can last for decades, many years may elapse before all current appliances are replaced. An ancillary point is that when a long-lived appliance is replaced, there is a singular opportunity to increase efficiency by choosing a more efficient model. If this opportunity is missed, it might be decades before another one arises.

Energy Use in U.S. Industry

The $2.6 trillion output of U.S. industry in 2006 was produced by diverse businesses with a wide array of products, processes, and ways of using energy. U.S. industry spends $200 billion per year to purchase 33 percent of the total energy used. About 8 quads of that energy are for feedstocks into the production of products, such as petrochemicals, fertilizer, and asphalt. The most energy-intensive industries are metals (iron, steel, and aluminum), petroleum refining, basic chemicals and intermediate products, glass, pulp and paper, and mineral products (cement, lime, limestone, and soda ash). In 2002, petroleum supplied 40 percent of industrial energy, and natural gas supplied 44 percent. Almost all of the coal used in the United States is for electricity generation, rather than for industrial use.

Because of a shift toward services and greater energy efficiency, energy use by industry is forecast to grow only 4 percent from 2007 to 2030 (EIA, 2009a). Nevertheless, U.S. industry is markedly less efficient in using energy than industry in other industrialized nations, due in part to the historical abundance of low-priced energy in this country. In addition, other industrialized nations impose high taxes on energy. In 2000, the Intergovernmental Working Group on Energy-Efficient and Clean Energy Technologies estimated that a portfolio of advanced technologies could reduce energy use by 16.6 percent by 2020. Using the latest projections by the Energy Information Agency, the savings would be 5.7 quads plus an additional 2 quads due to the increase in the use of combined heat and power (NRC, 2009). Table 2 is a summary of various estimates of increases in energy efficiency in U.S. industry by 2020.

Cross-cutting technologies, such as combined heat and power, better separation processes, advanced materials that resist corrosion and can withstand high temperatures, better steam and process heating technologies, new fabrication processes, and better sensors could lower energy use in many industries. As shown in Table 3, by 2020, improvements in energy efficiency could reduce energy use by 14 to 22 percent, compared to the usual projection, with rates of return of at least 10 percent. However, major barriers would have to be overcome to achieve these levels of improvement:

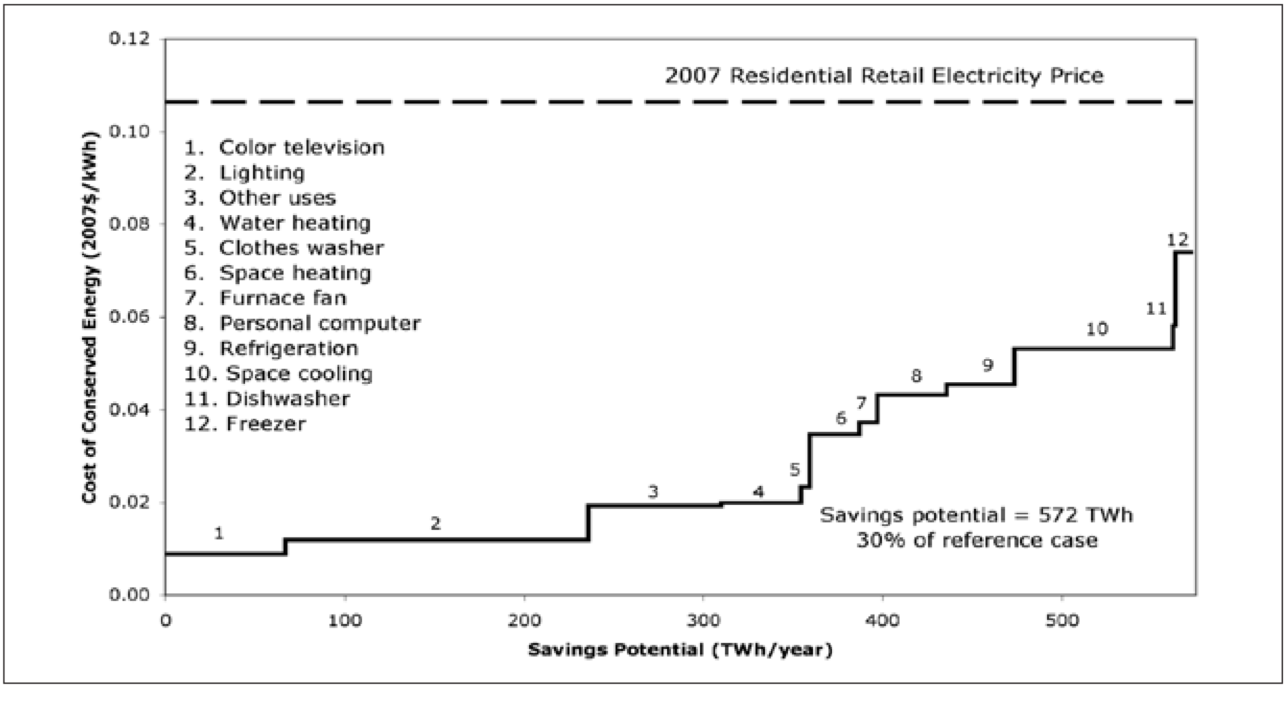


FIGURE 4 Potential electricity savings for residential products. Source: NRC, 2009.

TABLE 2 Potential for Energy-Efficiency Improvements in Industry by 2020: Sector-wide and for Selected Subsectors and Technologies (in Quads)

	CEF Study[a] Scaled to AEO 2008[b]	McKinsey and Company (2008)	Other U.S. Studies	Global Estimates from IEA (2007)
Petroleum refining	N/A	0.3	0.07–1.46 to 1.68–3.94	13–16%
Pulp and paper	0.14	0.6	0.53–0.85	15–18%
Iron and steel	0.21	0.3	0.76	9–18%
Cement	0.08	0.1	0.04 to 0.65	28–33%
Chemical manufacturing	N/A	0.3	N/A	13–16%
Combined heat and power	2.0	0.7		
Total Industrial Sector	7.7	4.9		18–26%
	(22.4%)	(14.3%)		

Source: Based on NRC, 2009.

[a] For CEF study, see Intergovernmental Working Group, 2000.

[b] AEO 2008, see EIA, 2008a.

- Because each industrial plant is unique, new technologies pose technical risks and may interrupt production or lower the quality of a product, even if they have been proven effective in other plants.
- Industry is looking for a much higher rate of return than 10 percent in allocating investment funds among competing projects.
- Plant managers are unlikely to have the discretion to invest in energy efficiency or reductions in emissions unless they are required to do so by regulation or ordered to do so by company management.
- Efficiency innovations often require specialized knowledge that many current plant managers do not have.
- If a new technology interrupts production, lowers product quality, or otherwise lowers the value of plant output, the costs could be much higher than the savings from energy efficiency.

Energy Use in Transportation

Modest improvements in efficiency will be made in some modes of transportation as new technologies are introduced and as research results are transferred. For example, the new 787 and 747-8 jets will provide a 15 to 20 percent increase in fuel economy compared to the models they replace. However, an increase in air traffic is expected to far outweigh improvements in efficiency, leading to greater fuel consumption overall.

Fuel accounts for a major proportion of annual costs in the trucking industry, which has always made fuel economy a priority. Modest improvements are expected in this sector, mostly from truckers shutting off their engines rather than idling when a truck is not moving.

Rail transportation and marine shipping have also put a premium on efficiency, and diesel-electric locomotives and diesel ship engines have improved efficiency over time in both sectors. The major potential for reducing fuel use in freight transport in the future will be from slower speeds and better integration among shipping modes. For example, freight could be carried by rail for the long part of a haul, with local pickup and delivery by truck. The widespread use of containers has removed many of the barriers to intermodal coordination.

Barriers to Energy Efficiency

Formidable barriers stand in the way of the implementation of energy-efficient changes. First, energy prices are artificially low because they do not account

TABLE 3 Summary of Potential Savings in Industry (estimated energy savings due to energy-efficiency improvements in industry)[a] (in Quads)

	Energy Use in Industry			Savings over Business as Usual (BAU) in 2020[a,b]
		BAU Projection (DOE/EIA Reference Case)		
Industry	**2007**	**2020**	**2030**	**Savings in 2020[a,b]**
Petroleum refining	4.09	6.07	7.27	0.77–2.81
Iron and steel	1.38	1.36	1.29	0.21–0.76
Cement	0.44	0.43	0.41	0.04–0.39
Bulk chemicals	6.85	6.08	5.60	0.30
Pulp and paper	2.15	2.31	2.49	0.53–0.85
Total savings for all industries (including those not shown)				4.9–7.7[c] 14%–22%

Source: NRC, 2009.

[a] Based on review of studies for specific major energy-using industries, for industrial combined heat and power (CHP), and for industry as a whole.

[b] Savings shown are for cost-effective technologies, defined as those providing an internal rate-of-return of at least 10 percent.

[c] Includes 0.7–2.0 quads from CHP systems.

for environmental or energy-security externalities, such as air and water pollution, greenhouse gas emissions, and other environmental effects, and the costs of ensuring a stable supply of energy imports. A high price for energy, such as the prices in July 2008 for gasoline, natural gas, and coal, would justify the implementation of more efficiency measures. In addition, high prices tend to focus attention on efficiency and conservation, an important factor in potential savings. Unfortunately, wildly fluctuating prices in 2008 wound up undermining the ability of producers and consumers to predict future prices and thus tended to also undermine arguments for investments in efficiency.

Second, current tax policies encourage expenditures on energy rather than on greater efficiency. Energy expenses are considered a current cost while expenditures for efficiency must be depreciated over time.

Third, in most states, utilities' profits go up when they sell more electricity or natural gas, and, logically, they go down by encouraging efficiency. Some states, such as California, have changed the compensation rules to motivate utilities to invest in efficiency rather than increasing energy use. A related issue has been that each utility has exclusive rights to sell its product in its service area, which has impeded the development of combined heat and power, microgrids, and other energy-efficient technologies.

Fourth, the decision about whether to invest in energy efficiency is often made by someone other than the person paying the energy bill. For example, a landlord may select appliances, but the tenant pays for electricity. Similarly, architects and builders, who are motivated to keep the price of a building down, may choose windows, insulation, and other materials with a focus on minimizing first costs rather than minimizing lifetime costs.

Fifth, architects, builders, workers, and customers all need more and better information. If they do not understand the benefits of alternatives, they cannot make informed choices.

Sixth, because energy expenditures are often a small part of the cost of occupying a residence or running a business, they often get little attention.

Seventh, energy-efficient appliances must be mass produced to be competitive with less efficient appliances. This cannot happen, however, until a substantial number of customers express a desire for these products. This chicken-and-egg problem can keep products with important advances from entering the market.

Finally, energy-efficient alternatives often have a higher initial price tag than less efficient products. If

TABLE 4 Estimates of Energy Savings from Major Energy-Efficiency Policies and Programs

Policy or Program	Electricity Savings (TWh/yr)	Primary Energy Savings (Quads/yr)	Year
CAFÉ vehicle-efficiency standards	—	4.80	2006
Appliance efficiency standards	196	2.58	2006
PURPA and other CHP initiatives	—	1.68	2006
ENERGY STAR labeling and promotion	132	1.52	2006
Building energy codes	—	1.08	2006
Utility and state end-use efficiency programs	90	1.06	2006
DOE industrial efficiency programs	—	0.40	2005
Weatherization Assistance Program	—	0.14	2006
Federal Energy Management Program	—	0.11	2005
TOTAL	—	13.37	—

Source: NRC, 2009.

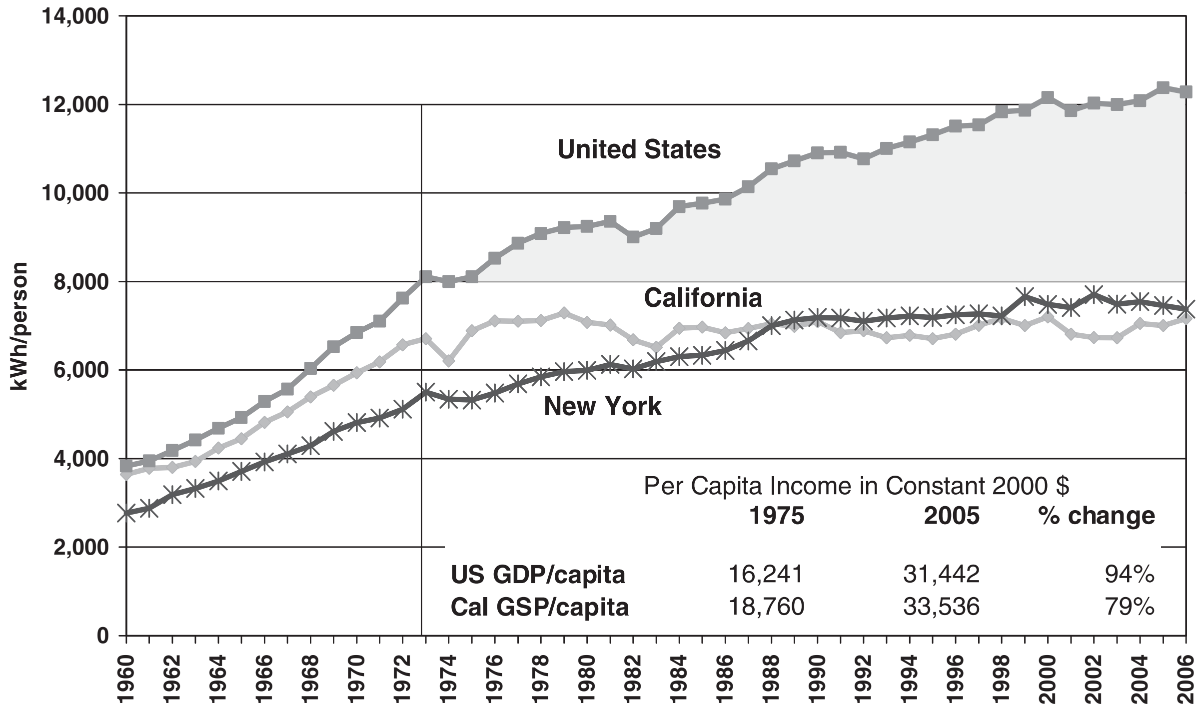


FIGURE 5 Per-capita electricity consumption in California, New York, and the United States as a whole, 1960–2006 (not including on-site generation). Source: NRC, 2009.

customers cannot afford the higher price or if they have to pay credit card interest rates, they are not likely to choose the energy-efficient alternative.

Drivers of Energy Efficiency

Despite these barriers, substantial progress has been made in energy efficiency, as shown by the drop in energy intensity of the U.S. economy. New energy-efficient technologies (e.g., electric arch furnaces rather than integrated steel mills) are being adopted, even though energy efficiency is not the major reason. Another driver has been intense competition. Sometimes, although energy savings for a plant may be small, they can make the difference between a facility that becomes profitable and one that cannot compete.

Regulations, such as vehicle fuel-economy standards address energy efficiency directly. Since environmental emissions generally consist of waste raw materials and fuel, regulations for air and water pollution discharges often encourage more efficient use of these inputs, including better energy efficiency.

Appliance and building codes have been particularly important in improving energy efficiency (see Figure 3 for refrigerators). In these cases, standards have overcome barriers to bringing more efficient, cheaper products to market. However, regulation is a deceptively simple tool for change; in fact, it cannot work without the cooperation of both industry and consumers.

A less heavy-handed innovation has been providing customers with information (e.g., Energy Star labels) about how much energy a product uses. However, customers must also be educated about how to use this information. Pressure from educated consumers and investors has motivated many companies to improve their energy efficiency and the energy efficiency of their products.

Table 4 shows estimates of energy savings as a result of government policies. California and New York, which have aggressively promoted electricity savings, have held electricity use per capita nearly constant for more than two decades. As a result, their use per capita is 40 percent below the national average (Figure 5).

Conclusion

The AEF Energy Efficiency Panel concluded that existing technology, or technologies that will be developed in the normal course of business, could save 30 percent of the energy that would have been used by 2030 under current policies and assumptions. About half of that efficiency increase could be achieved by 2020. The energy savings represent a savings in dollars as well as in energy. However, formidable obstacles must be overcome to realize these savings, which will require major public and private support, including product labeling, efficiency regulation, changes in tax policy, and educating and informing designers, builders, operations personnel, and customers about the benefits of energy efficiency.

Finally, special attention must be paid to the design and purchase of long-lived assets, from buildings and automobiles to refrigerators and air conditioners. Because of their long lifetimes, when an energy-inefficient product is purchased, the inefficiency cannot be eliminated until the product is replaced, which may take decades. Therefore, the energy efficiency of long-lived products should be improved, and purchasers should not only have the information they need to appreciate their energy efficiency, but should also have incentives to choose them over less efficient, often lower priced, competitors.

References

EIA (Energy Information Administration). 2008a. Annual Energy Outlook 2008 with Projections to 2030. Available online at *http://www.eia.doe.gov/oiaf/archive/aeo08/index.html.*

EIA. 2008b. Short-Term Energy Outlook. Available online at *http://www.eia.doe.gov/emeu//aer/pdf/pages/sec1_5.pdf.*

EIA. 2009a. Annual Energy Outlook 2009 with Projections to 2030. Available online at *http://www.eia.doe.gov/oiaf/aeo/demand.html.*

EIA. 2009b. Energy Intensity Using Purchasing Power Parities (Btu per Year (2000) U.S. Dollars Market Exchange Rates). International Energy Statistics. Available online at *http://tonto.eia.doe.gov/cfapps/ipdbproject/iedindex3.cfm?tid=44&pid=47&aid=2&cid=&syid=2002&eyid=2006&unit=BTUPUSDM.*

EIA. 2009c. Total Primary Energy Consumption per Capita (Btu per year (2000) U.S. Dollars Purchasing Power Parities). Available online at *http://tonto.eia.doe.gov/cfapps/ipdbproject/iedindex3.cfm?tid=44&pid=45&aid=2&cid=&syid=2002&eyid=2006&unit=BTUPUSDP.*

IEA (International Energy Agency). 2004. Oil Crises and Climate Challenges: 30 Years of Energy Use in IEA Countries. Paris: Organization for Economic Cooperation and Development.

Intergovernmental Working Group on Energy-Efficient and Clean Energy Technologies. 2000. Scenarios for a Clean

Energy Future. ORNL/CON-476. Oak Ridge, Tenn.: Oak Ridge National Laboratory.

McKinsey and Company. 2008. The Untapped Energy Efficiency Opportunity of the U.S. Industrial Sector: Details of Research, 2008. New York: McKinsey and Company.

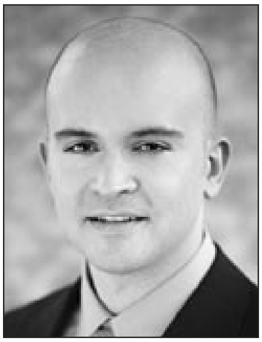
NRC (National Research Council). 2009. Realistic Prospects for Energy Efficiency in the United States. Washington, D.C.: National Academies Press.

Schurr, S., and B. Netschert. 1960. Energy in the American Economy, 1850–1975: An Economic Study of Its History and Prospects. Baltimore, Md.: Johns Hopkins University Press.

Taub, E.A. 2009. Industry Looks to LED Bulbs for the Home. New York Times, May 11, 2009, p. B6.

The chemical industry is finding creative ways to reduce energy usage and reshape product life cycles.

Improving Energy Efficiency in the Chemical Industry



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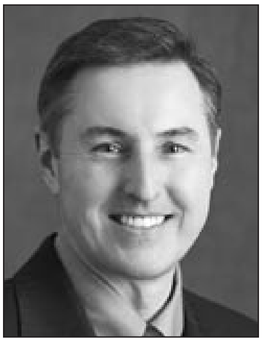

William F. Banholzer

Jeremy J. Patt and
William F. Banholzer

The chemical industry accounts for 6 percent of energy usage in the United States (Wells, 2008). Approximately half of this energy is contained in hydrocarbon raw materials—primarily from oil and natural gas. The other half is used to transform raw materials into useful chemical products through reaction and purification steps (Neelis et al., 2007).

The key difference between the chemical industry and the fuels sector is that, in the production of chemicals, most of the enthalpy of the starting materials is preserved in the final products. In the fuels sector, the enthalpy is completely consumed to generate energy. Since both sectors rely on the same hydrocarbon resources, conservation in the chemical sector also benefits the fuels sector.

Because of the magnitude of its energy consumption, the chemical industry is motivated to conserve, and U.S. producers have reduced their fuel and power usage per unit output by nearly half since 1974 (ACC, 2009). But opportunities for energy savings go beyond internal consumption. Because more than 96 percent of manufactured goods involve chemistry (Durbin, 2008), the industry can also improve energy usage by consumers through the careful shaping of the product life cycle.

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In this article, we describe how the industry is improving energy efficiency in five areas: improving existing processes, commercializing new processes, recycling waste, investing in renewable raw materials, and creating products that enable energy savings. Specific examples from Dow Chemical Company, the largest U.S. chemical company, are used as a proxy for the industry.

Improving Existing Production Processes

In 2008, Dow's total energy bill was $27 billion, by far the largest component of production costs and equal to about half of total revenues. In its global operations, Dow uses the energy equivalent of 850,000 barrels of oil per day—more than the oil consumption of some countries, such as the Netherlands and Australia.

Dow publishes the energy used per pound of product on its sustainability web page (*http://www.dow.com/commitments/index.htm*). Since 1994, Dow has reduced its energy intensity by 22 percent through a structured program targeting process improvements. This has saved 1.6 quadrillion BTUs, equivalent to the energy required to generate all of the residential electricity used in California for one year. The savings have totaled $8.6 billion on an investment of $1 billion.

Substantial improvements in energy efficiency have been made by improving existing processes and commercializing new processes.

Advanced Control and Optimization

One improvement that is a major change throughout the chemical industry is the recent and ongoing implementation of advanced control and optimization (AC&O). Traditional process control involves monitoring and manipulating parts of the chemical plant, for example setting reactor temperature and pressure to control product yield. With implementation of AC&O, engineers create a predictive model for the entire process based on either matrix algebra or a set of first-principle equations. This is considered a closed-loop application, meaning the model reads in values from the plant, evaluates the operating conditions, calculates the conditions under which the plant will make the most money, then moves the plant to the new target conditions. Typically there are hundreds of measured inputs—such as temperatures, pressures, flow rates, and compositions. Additional inputs include changing economic values, such as current prices and supply/demand constraints for raw materials, utilities, and products. The model manages hundreds of outputs for adjusting conditions of the process and includes built-in constraints to ensure the safety and operability of the target conditions.

Because a typical plant is very complex, with nonlinear and multivariate interactions, it is impossible for a human operator to select the best operating conditions. For example, restarting a complicated plant with many recycle streams can take several days to reach full production rates. AC&O can press the limits of stability and cut this time in half. Dow has found that adding AC&O applications improves production capacity by 3 to 5 percent and decreases energy intensity by 4 to 6 percent. Dow's cumulative savings from AC&O are projected to be more than $1 billion in 2009.

Reducing Gas Flaring

Another area of close attention in the chemical industry is the reduction of flaring, the intermittent burning of flammable gases or liquids. Flaring does not occur during normal steady-state operations, but does occur in episodes when a plant is operating outside its intended design conditions, such as unplanned overpressure of plant equipment during a process upset. The relief valves that protect equipment are tied into the flare system. Usually the flared material is combusted at the tip of a tall tower called a flare stack.

Another reason for gas flaring is the production of unusable "off-spec" material that has no other place to go and cannot be stored or purified. This usually occurs during process upsets or when a plant is restarting after a shutdown. There are two ways to reduce flaring—by maximizing the stability of plant operations to avoid upset conditions and by finding practical opportunities for storing, purifying, or reusing unwanted materials.

A typical world-scale olefins plant may flare several thousand metric tons of hydrocarbons per year. Olefins are the basic building blocks of many important chemical derivatives, including plastics, and Dow operates more than a dozen olefins plants around the world. For several decades, there has been an intense focus on reducing the amount of flaring at these sites.

One successful initiative was replacing gas turbines to improve the reliability of a plant. Gas turbines, although they are highly efficient, are more complicated than steam turbines. They also cause more plant outages, which can result in large flaring events. A single large flaring event can wipe out marginal savings from better turbine efficiency. After installing steam turbines at a plant in Plaquemine, Louisiana, the time between plant outages increased from approximately 250 days to several years.

A second major initiative to reduce flaring has been gas recycling. At olefins plants in Canada, Argentina, and the United States, Dow has found ways to recycle gas back into the system rather than sending it to the flare. As a result of these initiatives and other targeted projects, Dow has reduced the rate of flaring at its olefins facilities by 20 percent since 1998.

Improving the Yield of Raw Materials

There are many ways to improve the efficiency of a plant, and often the most significant benefits are realized by improving the yield of raw materials to desired products. Throughout the chemical industry, companies are developing better catalysts that can increase yields for existing plants. One recent innovation relates to the hydroformylation process, the reaction of propylene with syngas (a mixture of hydrogen and carbon monoxide) to produce butyraldehyde isomers. The highest value isomer is normal-butyraldehyde, which is converted to 2-ethylhexanol (2EH) for use in the production of plasticizers that add flexibility to PVC plastics.

A new hydroformylation catalyst was recently introduced and is cooperatively offered by Dow Technology Licensing and Davy Process Technology. This catalyst is based on rhodium modified with a biphosphite ligand with a unique geometry that selectively hinders molecular movement around the rhodium center. This improves yield to normal-butyraldehyde over iso-butyraldehyde based on the different geometries of the two isomers.

NanYa Plastics has selected the new catalyst technology to retrofit and expand its existing plant in Taiwan. With startup targeted for early 2010, the new catalyst will more than double the production ratio of normal- to iso-butyraldehyde, providing a selectivity of 30:1. This will reduce the amount of propylene required for making 2EH by more than 6 percent compared to the current operation. Considering the annual 2EH production capacity of 200,000 metric tons, this retrofit will provide a significant reduction in propylene consumption.

Commercializing New Processes

The chemical industry has achieved tremendous efficiency gains by introducing new breakthrough processes. One very recent production technology was developed jointly by BASF and Dow. The development program began in 2003, construction broke ground in 2006, and the startup phase for the production plant was completed in 2009. The plant, located at the BASF site in Antwerp, Belgium, produces propylene oxide (PO) with an annual capacity of 300,000 metric tons (Figure 1).

PO, one of the top 50 largest-volume chemical intermediates produced in the world, is a key raw material for the production of a wide range of industrial and commercial products, including polyurethanes, propylene glycols, and glycol ethers. Historically, the production of PO has required either the production of significant volumes of co-products or the recycling of organic intermediates. The new process is based on the reaction of

FIGURE 1 The new HPPO plant at the BASF site in Antwerp, Belgium, completed the startup phase in 2009. With a new process for producing propylene oxide jointly developed by BASF and Dow, wastewater is reduced by up to 80 percent, and energy use is reduced by 35 percent compared to conventional processes. Source: BASF.

hydrogen peroxide, a clean, versatile, environmentally benign oxidant, and propylene to PO. The reaction is facilitated by a proprietary titanium-silicalite catalyst.

In the hydrogen peroxide-PO (HPPO) process, propylene is contacted with hydrogen peroxide in a tubular reactor at moderate temperature and low pressure over a solid catalyst. The reaction occurs in the liquid phase using methanol as a solvent. The process is characterized by both high conversion and high selectivity to the PO, made possible by the unique catalyst material. The co-product of this reaction is water. Hydrogen peroxide is completely converted while the excess unconverted propylene is recycled back to the reactor inlet. The crude PO product is purified by distillation, and the methanol solvent is recycled. The final water stream is discharged to a water treatment unit.

The integration of raw material for the HPPO process is simple—hydrogen peroxide and propylene are the only raw materials. Thus there is no need for additional infrastructure or markets for co-products. HPPO has significant efficiency benefits over conventional processes. Wastewater is reduced by as much as 80 percent, and energy use is reduced by 35 percent. The simple integration of the raw materials and the avoidance of co-products has reduced the infrastructure requirements and physical footprint of the plant.

Recycling Waste

The chemical industry continues to find creative ways of recycling and reusing waste streams. Dow recently began operating a novel system for reusing municipal wastewater at the Terneuzen site in the Netherlands. In collaboration with local authorities and a local water producer, this site accepts more than 2.6 million gallons of municipal household wastewater every day. The local water producer removes residual contaminants, and Dow then uses more than 70 percent of this water to generate high-pressure steam. After the steam is used in production processes, the water is again used in cooling towers until it finally evaporates into the atmosphere.

This is the first time municipal wastewater is being reused on such a large scale in the industry. Three million tons of water per year was previously discharged into the North Sea after a single use. Now this water is recycled for two more applications and has resulted in 65 percent less energy use at this facility compared to the alternative option of desalinating seawater. The reduction in energy use is the equivalent of lowering carbon dioxide emissions by 5,000 tons per year. This concept can be applied at other locations around the world.

Another unique case of recycling is the use of landfill off-gas (Figure 2). Instead of using natural gas, Dow has

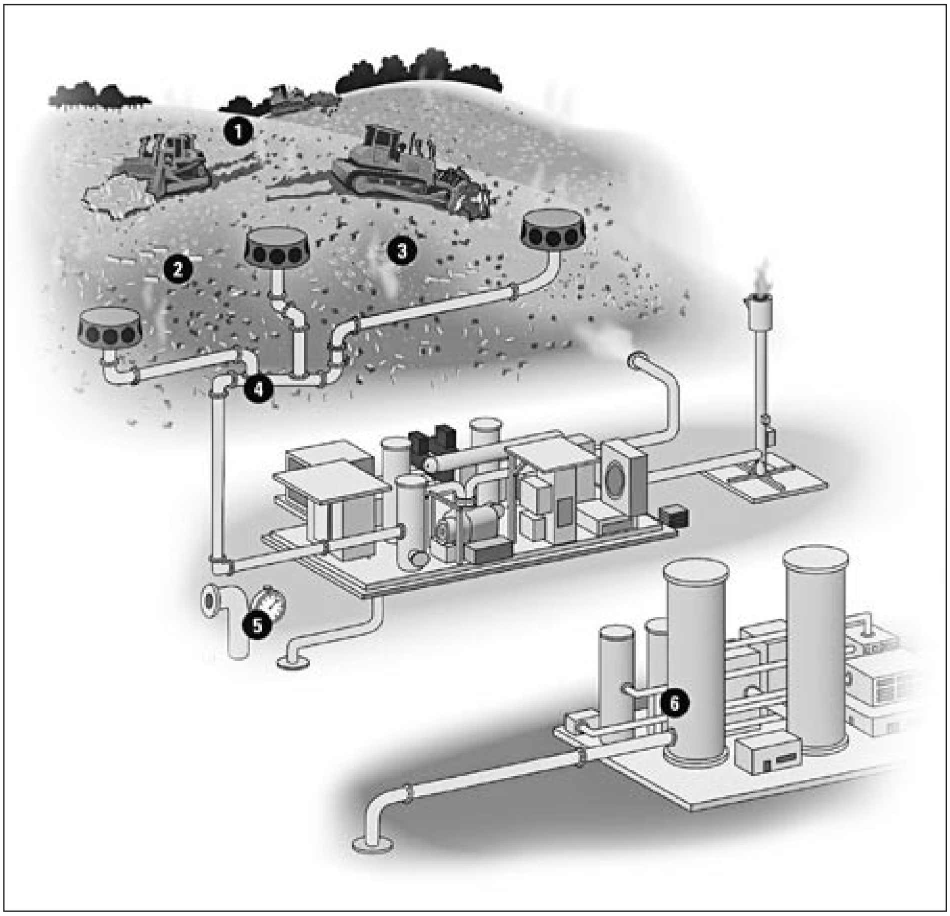


FIGURE 2 Recycling landfill off-gas for energy in Dalton, Georgia. (1) Landfill waste is structured. (2) Anaerobic bacteria decompose the municipal solid waste. (3) Methane off-gas is generated. (4) A system of pipes and blowers collects gas and delivers it to a central location. (5) Gas is used as fuel to make steam. (6) Steam is used by the Dow emulsion polymers plant to manufacture latex carpet backing.

piped methane off-gas from a local landfill to its Dalton, Georgia, latex manufacturing plant. The gas is used as fuel to generate steam for the production of latex carpet backing. This site is expected to use approximately 160 billion BTUs per year of landfill gas (the energy equivalent of 1.4 million gallons of gasoline) that would otherwise be emitted into the atmosphere.

Municipal landfills are the largest source of human-generated methane emissions in the United States. As a greenhouse gas, methane has more than 20 times as much global warming potential as carbon dioxide. By capturing and burning methane, the Dalton facility will reduce the use of fossil fuels and will reduce methane emissions from the landfill. The reduction of greenhouse gases is equivalent to 24 million pounds of carbon dioxide per year.

Investing in Renewable Raw Materials

Producing Epichlorohydrin from Glycerine

Many chemical companies are introducing more efficient processes based on renewable raw materials. One such process at Dow is used to make liquid epoxy resins, which are used in coatings, including marine and automotive applications. The new process involves making epichlorohydrin (EPI) from glycerine. EPI, a key raw material for epoxy resins, is traditionally made from propylene, a derivative of oil or natural gas liquids. In contrast, glycerine is a byproduct of biodiesel production, an alternative fuel made from renewable vegetable oil feedstocks. By using this new EPI process, Dow will reduce wastewater generation from a production facility by more than 70 percent, as compared to conventional technology. In addition, the formation of organic by-products will be considerably lower. Overall, the process will significantly reduce the environmental footprint of an EPI plant. Dow has announced plans for a world-scale glycerine-to-EPI unit in China, and a stand-alone pilot plant for this technology began operating in 2006 at Dow's production site in Stade, Germany.

Producing Polyols from Natural Oils

Another new investment in raw materials is the production of polyols from renewable natural oils, primarily soybean oils. Polyols are a component in the production of polyurethanes (foams and elastomers used in appliances, automotive parts, adhesives, building insulation, furniture, bedding, footwear, and packaging). Traditionally, polyols have been made from PO, a derivative of propylene. The new chemistry based on natural-oil feedstock will reduce the environmental impact of a facility compared to conventional production. The new chemistry is greenhouse-gas neutral and uses less than half of the petroleum-based fuel and raw materials of current technology.

Creating Products That Enable Energy Savings

Products made by the chemical industry are part of nearly all manufactured goods. Therefore, a chemical company has the opportunity to improve energy usage for the consumer through the careful shaping of the life cycle of its products. The creation of materials with unique properties and novel applications can yield significant energy savings for consumers everywhere. The following examples describe materials in the construction, automotive, packaging, refrigeration, water purification, and power generation sectors.

> *The new chemistry for producing polyols from natural-oil feedstock is greenhouse-gas neutral.*

Construction

One option for constructing a flat roof is a protected-membrane roof (PMR) system, that is, foamed polystyrene insulation that shields and protects the waterproof membrane of the roof. By contrast, a traditional system does not cover the membrane. The PMR roof protects the membrane against the most common causes of failure, including sun damage, extreme temperatures, weather, and foot traffic. Traditional flat roofs must be replaced every 7 to 10 years, while PMR roofs have lasted more than 30 years.

In addition, the polystyrene insulation is so durable it can be reused if the PMR roof membrane is ever replaced. Currently, 3 to 4 percent of all waste in U.S. landfills comes from old roofing material. Tripling the lifetime of a roof conserves raw materials and landfill space.

Automotive Manufacturing

Specialized polyurethane foams have been formulated to improve the stiffness and crash performance of vehicles. The foam, which is formulated to adhere to primed metal surfaces, is injected into automotive body cavities where it quickly cures to fill up to 100 percent of the cavity space. By improving the rigidity of body joints with foam, less metal is required to achieve equivalent strength. In one case, the use of polyurethane foam has enabled more than 36 pounds of net mass reduction per vehicle without lowering safety performance (Figure 3). A study of passenger vehicles has shown a 0.6 percent improvement in fuel economy for each 1 percent reduction in weight (Casadei and Broda, 2008).

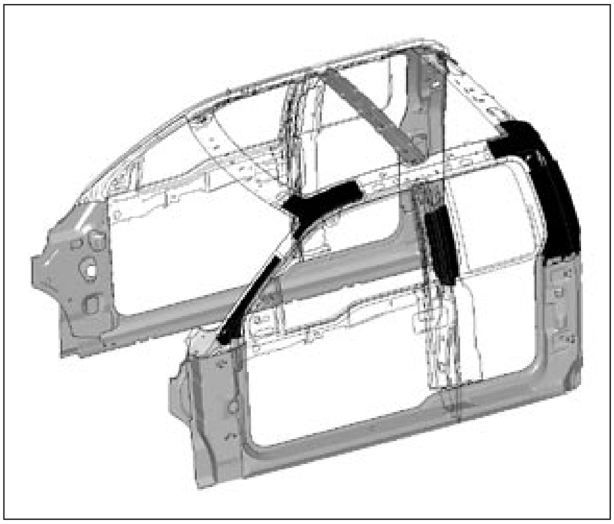


FIGURE 3 Use of structural foam in the pillars of a vehicle (darkened areas). In this case, the use of 4.3 lbs of specialty polyurethane foam yielded more than 36 lbs of net mass reduction as compared to conventional designs that use thicker metal to meet structural requirements.

Packaging Industry

Industrial stretch films manufactured from high-performance polyethylene resins are used to wrap and contain pallet loads during shipment and storage. Stretch films are also used for specialty wrapping applications for lumber, paper rolls, and agricultural silage. With improvements in resin design and polymer processing, industrial stretch film has been down-gauged (made thinner) by more than 25 percent in the last decade without compromising key properties, such as elongation and load-holding force.

This improvement has reduced the amount of polyethylene required for making stretch film by more than 1 billion pounds per year. The energy savings are equivalent to 293 million gallons of gasoline, or the heating and cooling of 643,000 homes for one year.

Refrigeration

A propylene glycol-based heat-transfer fluid is being used in Wal-Mart's experimental Supercenter store in Aurora, Colorado, in a refrigeration system for meat, dairy, produce, and other medium-temperature foods. Unlike traditional systems that require a separate motor for each cold case, the new system employs "secondary loop refrigeration," which requires only one motor. This setup, which is made possible by the unique properties of the heat-transfer fluid, has reduced energy consumption by up to 24 percent over traditional systems.

Water Purification

Reverse osmosis membranes are being used in three major wastewater reclamation and reuse facilities in the city of Beijing. These novel membranes consist of three layers (Figure 4). The major structural support is provided by a non-woven polyester web. Because this web is too irregular and porous to provide a proper substrate for the salt-barrier layer, a polysulfone interlayer is cast onto the surface of the web. The interlayer is an engineering plastic with pore diameters controlled to approximately 150 Angstroms. The final layer is a polyamide that acts as the salt barrier; this layer is only 2,000 Angstroms thick but can withstand high pressures because of the underlying support.

The membrane materials have been continuously updated and refined to improve efficiency through higher rejection, improved flux, and low fouling performance. They will be used to treat 45,000 cubic meters per day of water at the three sites—BeiXiaoHe Wastewater Treatment Plant, Beijing International Airport,

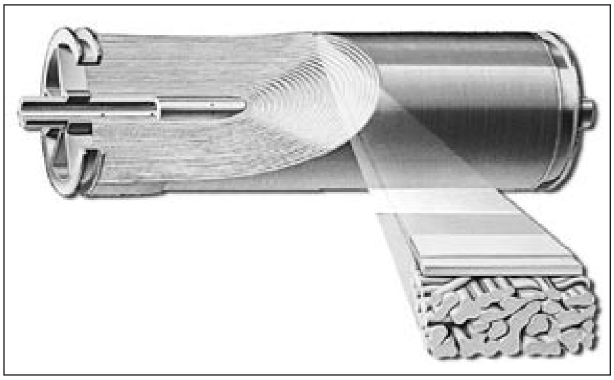


FIGURE 4 Reverse-osmosis membranes consist of (top to bottom) an ultra-thin polyamide barrier layer, a microporous polysulfone interlayer, and a high-strength polyester support web. The materials have been continuously updated and refined to provide higher rejection, improved membrane flux, and reduced fouling thus improving energy efficiency in the production of clean water.

and the Beijing Economic-Technological Development Area. This technology will help the city reach its goal of reusing half of its water, significantly extending a limited natural resource.

Power Generation

A solar energy initiative being led by Dow is intended to make solar energy cost competitive by 2015. The solar project is based on Dow's extensive materials, engineering, and design and fabrication technologies. The project will accelerate research and development on building-integrated photovoltaics (BIPVs), solar energy generating materials that can be incorporated directly into the design of commercial and residential building materials, such as roofing systems and exterior sidings. BIPVs eliminate the traditional trade-offs necessary with solar cells because they serve as the outer protective surface of the building and generate power.

Technology Pathway Partnerships for the solar initiative are comprised of more than 50 companies, 14 universities, three nonprofit organizations, and two national laboratories. The ultimate goal is to reduce the cost of electricity produced by photovoltaics from current levels of \$0.18 to \$0.23 per kWh to a target of \$0.05 to \$0.10 per kWh by 2015—a price that will be competitive in markets nationwide.

Conclusions

The chemical industry consumes large amounts of finite energy sources to process raw materials that are in limited supply. The industry has undertaken five major initiatives to improve its energy efficiency: (1) improving existing processes; (2) commercializing new processes; (3) recycling waste; (4) investing in renewable raw materials; and (5) creating products that enable energy savings. Innovation in all of these areas is an absolute necessity for long-term sustainability.

References

ACC (American Chemistry Council). 2009. American Chemistry is Essential: Industry Fact Sheet. Available online at *http://www.americanchemistry.com/s_acc/ bin.asp?CID=1772&DID=6573&DOC=FILE.PDF*.

Casadei, A., and R. Broda. 2008. Impact of Vehicle Weight Reduction on Fuel Economy for Various Vehicle Architectures. Research Report Conducted by Ricardo Inc. for The Aluminum Association, Project FB769 RD.07/71602.2. Available online at *http://www.autoaluminum.org/downloads/AluminumNow/Ricardo%20Study_with%20cover.pdf*.

Durbin, M. 2008. Statement of Marty Durbin before the U.S. House of Representatives Energy and Commerce Committee Subcommittee on Environment and Hazardous Materials. Legislative Hearing on H.R. 5533 and H.R. 5577, June 12, 2008.

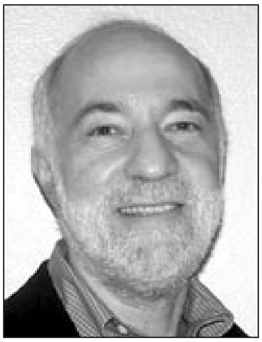
Neelis, M., M. Patel, K. Blok, W. Haije, and P. Bach. 2007. Approximation of theoretical energy-saving potentials for the petrochemical industry using energy balances for 68 key processes. Energy 32(7): 1104–1123.

Wells, R. 2008. Statement for the Record by Rich Wells for the U.S. Congress Select Committee on Energy Independence and Global Warming. Hearing on What's Cooking with Natural Gas in Energy Independence and Global Warming Solutions, July 30, 2008.

Trade-offs among performance, size, and fuel consumption in light-duty vehicles will be a critical policy challenge.

Energy Efficiency in Passenger Transportation

Daniel Sperling and Nic Lutsey



Daniel Sperling

Nic Lutsey

Transportation accounts for approximately one-third of greenhouse gas (GHG) emissions in the United States, two-thirds of oil consumption, and about half of urban air pollution (Davis et al., 2008; NRC, 2006; EPA, 2008). In addition, GHG emissions are increasing faster in transportation than in any other sector, making it a prime target for changes in energy and climate policy. As a result of increased use of energy-intensive modes of transport, especially private cars and trucks, bus and rail transit now account for less than 3 percent of passenger travel in the United States.

Reducing oil use and GHG emissions in transportation is difficult for two basic reasons: (1) as a derived demand linked to almost all other economic activity, travel demand has proven to be both strong and inelastic; and (2) unlike other large energy-using sectors that can operate with a variety of commercial fuels, vehicles operate almost exclusively on oil-based fuel.

Introducing new fuel-efficient propulsion technologies and low-carbon fuels has been difficult because of poor coordination between fuel and vehicle industries, the necessity of large upfront investments in infrastructure, and entrenched consumer expectations and habits. To make matters

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worse, petroleum production is becoming *more* rather than *less* carbon intensive as easily accessed, high-quality reserves are depleted, and producers tap into remote sources of fossil energy that require additional refining to upgrade fuel quality.

Despite this rather bleak scenario, there are many attractive opportunities for reducing oil use and GHG emissions. In this article we focus on the largest component of the transportation sector, light-duty vehicles,[1] which account for more than half of the oil consumption and almost a quarter of GHG emissions in the United States (EPA, 2008). In addition, we define energy efficiency to include: (1) improvements in conventional vehicles and the introduction of advanced, high-efficiency propulsion technologies based on non-petroleum fuels; (2) changes in "on-road" operational practices; and (3) system improvements that result in decreased vehicle use.

Improvements in Conventional Vehicles

Internal Combustion and Compressed Ignition Engines

Incremental improvements in conventional vehicles include more efficient combustion (e.g., variable valve systems, gasoline direct injection, cylinder deactivation, and homogeneous-charge compression ignition), turbocharging, smart cooling systems, reduced engine friction, more efficient transmissions (e.g., 5- and 6-speed automatic, automated manual, and continuously variable systems), lightweight materials and designs, and "slippery" aerodynamics.

Efficiency can be improved by 10 to 15 percent in the near term (by 2020) and by an additional 15 to 20 percent in the longer term (2030) with improvements in conventional vehicles with internal combustion engines (ICEs) (NRC, 2009). The use of diesel (compressed-ignition) engines could provide small additional improvements. Most studies have shown that the fuel savings from these improvements far outweigh their higher cost (Lutsey and Sperling, 2009).

Electric-Drive Propulsion Technologies

Much greater GHG reductions are possible with electric-drive propulsion technologies. These include hybrid gasoline-electric vehicles (HEVs), plug-in hybrids (PHEVs) that use electricity and petroleum fuels, battery electric vehicles (BEVs), and hydrogen-powered fuel-cell vehicles (HFCVs).

HEVs are fueled by gasoline but are propelled by ICEs coupled with electric motors and batteries. Usually both systems can drive the vehicle, with the ICE being used for recharging the batteries. The primary efficiency benefits of a gasoline hybrid are realized by using the electric motor and battery to eliminate idling, provide regenerative braking, downsize engines, and create more efficient engine operating conditions. A wide variety of hybrid technologies are possible, from simple systems that reduce fuel use by 4 to 6 percent by eliminating engine idling to more complex systems with bigger batteries, such as the Toyota Prius, that reduce fuel use by 30 percent. Another 10 percent in efficiency could be gained with a diesel engine, but at considerably higher cost.

Improvements in conventional vehicles can deliver a 10 to 15 percent improvement in fuel use and lower emissions by 2020.

The next level of vehicle electrification is PHEVs, which carry a much larger battery pack that is rechargeable from an external source of electricity. PHEV batteries can be sized to power all-electric driving for 60 miles or more, and they can reduce petroleum consumption by up to 75 percent over gasoline vehicles, depending on the size of the onboard battery. The corresponding reduction in GHG emissions depends on the GHG intensity of the electricity used to charge the battery. PHEVs are likely to be introduced into the U.S. market in modest numbers beginning in 2011, but the development of a mass market for them will require batteries that last for 10 years or more and cost much less than today's batteries.

Fully electrified vehicles use batteries and/or fuel cells (and possibly ultracapacitors),[2] do not have combustion

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[1] "Light duty vehicles," here and in most regulatory frameworks, include passenger cars and light trucks (including minivans, pick-up trucks, and sport utility vehicles) with Gross Vehicle Weight Ratings of less than 8,500 pounds.

[2] Fully electric vehicles could alternatively use electricity from overhead or adjacent wires or wires in the pavement, as some buses and most urban rail vehicles do.

engines, and have a "tank-to-wheel" vehicle efficiency at least twice that of conventional gasoline vehicles. A large number of small companies already sell small BEVs, and many major automotive companies have plans to start selling them in small numbers beginning in about 2011. In the foreseeable future, mass-market BEVs will be small, similar in size to the Mercedes Smart, with driving ranges of up to about 120 miles per charge.

Hydrogen Fuel Cell Vehicles

HFCVs convert hydrogen into electricity. Fuel cell systems are 2 to 3 times as energy efficient as combustion engines and emit no GHGs—although, like electric cars, their life-cycle GHG emissions depend on how the hydrogen is produced. Most major automotive companies have large fuel-cell development programs and have built and tested demonstration fleets. The principal challenges are the durability and cost of fuel cells, the cost of storing hydrogen in fueling stations and on board the vehicle, and the deployment of a hydrogen supply and fueling infrastructure.

Summary

Table 1 shows plausible levels of reductions in petroleum use and GHG emissions from improvements in vehicle technology (NRC, 2009). The evolutionary improvements described above can reduce fuel consumption of a gasoline ICE vehicle by up to 35 percent in the next 25 years. Diesel ICE vehicles will also continue to be more efficient, but the gap between diesel and gasoline engines is likely to narrow. Hybrid vehicles have a greater potential for improvement and can deliver deeper reductions in vehicle fuel consumption, although they continue to depend on petroleum (or alternative liquid fuels, such as biofuels). BEVs and HFCVs represent a leap forward in efficiency but will be considerably more expensive initially. They offer the additional advantages of zero oil use and zero tailpipe emissions and, if electricity and hydrogen can be produced with few GHG emissions, they would also dramatically reduce total life-cycle GHG emissions.

TABLE 1 Plausible Reductions in Petroleum Use and GHG Emissions from Improvements in Vehicle Efficiency in the Next 25 Years

	Petroleum Consumption (gasoline equivalent)		**Greenhouse Gas Emissions (per distance traveled)**	
Propulsion System	**Relative to Current Gasoline ICE**	**Relative to Gasoline ICE in 2035**	**Relative to Current Gasoline ICE**	**Relative to Gasoline ICE in 2035**
Current gasoline ICE	1	—	1	—
Current diesel engine	0.8	—	0.8	—
Current hybrid	0.75	—	0.75	—
Advanced gasoline ICE	0.65	1	0.65	1
Advanced diesel engine	0.55	0.85	0.55	0.85
Advanced hybrid (HEV)	0.4	0.6	0.4	0.6
Plug-in hybrid (PHEV)	0.2	0.3	0.35–0.45	0.45–0.7
Battery electric vehicle (BEV)	none	—	0.35–0.5	0.55–0.75
Hydrogen fuel cell vehicle (HFCV)	none	—	0.3–0.4	0.45–0.60

Sources: Bandivadekar et al., 2008; NRC, 2009.

Note: Estimates are based on the assumption that vehicle size and performance (e.g., power-to-weight ratio, acceleration) remain at current levels, that electricity is produced with the current energy mix, and that hydrogen is produced from natural gas. Considerably larger reductions are possible if vehicle weight and power, as well as the carbon intensity of electricity, hydrogen, and biofuels, are all reduced.

Gains from Improvements in Vehicle Technologies

An obvious way to reduce fuel consumption is to reduce the weight of the vehicle. A common rule of thumb is that a 10 percent reduction in weight can reduce fuel consumption by 5 to 7 percent, when accompanied by appropriate engine downsizing at constant performance. Still further reductions are possible with reductions in power and vehicle size, both of which have increased dramatically since the early 1980s. Today's average car accelerates from a standstill to 60 miles per hour in about 9.5 seconds. An average car in the mid-1980s required 14.5 seconds—and was much lighter.

Improvements in efficiency do not automatically translate into reductions in oil use and GHG emissions. From the mid-1980s to the early 2000s, efficiency improved considerably in a technical sense (measured as output per unit of energy input), but fuel consumption per vehicle mile did not change. This apparent anomaly occurred because efficiency gains were consumed by increases in vehicle size and improvements in performance (An and DeCicco, 2007; Lutsey and Sperling, 2005). As long as vehicle manufacturers compete on, and consumers continue to expect, improvements in performance, government intervention will be necessary to promote or require reductions in fuel consumption. Making tradeoffs among performance, size, and fuel consumption will be a critical policy challenge.

Still further reductions in GHG emissions are possible if fuels themselves are changed. If energy efficiency in the extraction and processing of fuels is improved, or if lower carbon feedstocks are used to produce fuels, then total energy use and GHG emissions would be lower (Table 2). Indeed, the energy and GHG intensity of electricity and hydrogen varies considerably. In California, for instance, only 15 percent of the electricity consumed in the state is generated from high-carbon coal, compared to more than 80 percent from coal in many other states.

We can reasonably assume that the carbon intensity of electricity and other fuels will decrease over time as incentives and requirements for renewable electricity and low-carbon fuels are put into place. The same

TABLE 2 Estimated Incremental Cost of Advanced Vehicles in the Next 25 Years Relative to a Baseline 2005 Standard Gasoline Vehicle

	Conservative Incremental Retail Price[a] (2007 dollars)		Optimistic Incremental Retail Price[b] (2007 dollars)	
Propulsion System	Cars	Light Trucks	Cars	Light Trucks
Current gasoline ICE	0	0	0	0
Current diesel ICE	1,700	2,100	1,500	1,900
Current hybrid vehicle	4,900	6,300	4,400	5,700
Advanced gasoline	2,000	2,400	1,800	2,200
Advanced diesel	3,600	4,500	3,000	4,000
Advanced hybrid vehicle (HEV)	4,500	5,500	2,500	3,000
Plug-in hybrid (PHEV)	7,800	10,500	3,900	5,300
Battery electric vehicle (BEV)	16,000	24,000	8,000	12,000
Hydrogen fuel cell vehicle (HFCV)	7,300	10,000	4,500	6,200

[a] Bandivadekar et al., 2008; NRC, 2009.

[b] Based on technology, learning, and longer-term engineering cost reductions: 10 percent cost reduction from gasoline and diesel technologies; midterm battery costs based on Kalhammer et al. (2007), Kromer and Heywood (2007), and EPRI (2002); midterm fuel cell vehicle costs based on NRC (2008), and Kromer and Heywood (2007).

Note: To obtain the price increments of an advanced technology vehicle relative to a future (improved) ICE vehicle, subtract $2000 (car) or $2,400 (truck) for the conservative projections.

forceful efforts that are being made to improve vehicle efficiency will eventually carry over to energy suppliers. With low-carbon electricity and hydrogen, it would be possible to reduce life-cycle GHG emissions from new vehicles by 80 percent or more by 2050.

Cost Considerations

Advanced vehicle and fuel technologies require large initial costs—especially for the development of electricity and hydrogen storage systems and fuel cells. Based largely on studies at MIT (Bandivadekar et al., 2008), a National Research Council (NRC) committee estimated the cost of future vehicles, presented as incremental increases in retail prices relative to a 2005 baseline gasoline ICE vehicle (shown in the left-hand columns of Table 2). These estimates depend on rates of engineering development and technology deployment and are subject to considerable uncertainty. The right-hand columns show a somewhat more optimistic estimate of future costs.

Table 2 shows that improved gasoline and diesel engines and gasoline hybrids would cost 10 to 30 percent more than typical current gasoline vehicles. The price difference is estimated to shrink to 5 to 15 percent in the midterm future. Longer term options such as plug-in hybrid and fuel-cell vehicles are estimated to cost 25 to 30 percent more than a future gasoline vehicle. Full-sized BEVs with standard performance would be much more costly, and thus most future BEVs will likely be small city cars with reduced ranges.

The additional cost of fuel-saving technologies will largely be offset by fuel savings over the lifetime of the vehicle, but not in all cases. Longer term options such as PHEVs and HFCVs are estimated to pay back 50 to 70 percent of the increase in cost at $2.50 per gallon. At $5.00 per gallon, all technologies except diesel vehicles and (full-size) BEVs would fully pay back the initial retail price increase.

Overall, the estimates in Table 2 suggest that evolutionary improvements in gasoline ICE vehicles are likely to be the most cost-effective option for reducing petroleum consumption and GHG emissions in the near term. As advanced technologies improve, and if larger reductions in oil use and GHG emissions are deemed necessary (and supported by incentives, regulations, and other policies), then PHEVs, BEVs, and HFCVs will gradually be introduced.

Market Penetration

Advanced-technology vehicles face many barriers to capturing market share, such as high initial cost, safety concerns, fuel availability, reliability and durability concerns, and lack of awareness. Because all advanced technologies will be competing against steadily improving gasoline ICE vehicles, market penetration rates are likely to rise slowly unless fiscal and/or regulatory policies are changed dramatically.

The NRC study of energy efficiency (2009) developed plausible estimates of market share for advanced vehicles (Table 3). If, as indicated below, aggressive climate and energy policies are adopted, the market shares of advanced-technology vehicles are likely to be much higher.

In December 2007, Congress passed a law requiring that fuel economy for new light-duty vehicles be improved by 40 percent by 2020 (from an average of 25 mpg to 35 mpg). California, followed by 12 other states, has adopted a law that would require even greater reductions (roughly 40 mpg by 2020), but these state laws are under litigation and federal review and have not been implemented as this article goes to press. Many other programs and policies to accelerate improvements in vehicle efficiency and reductions in emissions are also in various stages of implementation.

TABLE 3 Plausible Light-Duty Vehicle Market Shares with Advanced Technology by 2020 and 2035

Propulsion System	Plausible LDV Market Share by Given Model Year	
	2020	2035
Turbocharged gasoline	10–15%	25–35%
Diesels	8–12%	15–30%
Gasoline hybrids (HEVs)	10–14%	15–40%
Plug-in hybrids (PHEVs)	1–3%	7–15%
Hydrogen fuel cell vehicles (HFCVs)	0–1%	3–6%
Battery electric vehicles (BEVs)	0–2%	3–10%

Source: NRC, 2009.

One federal program, for example, offers large subsidies for advanced vehicles (e.g., $7,500 for PHEVs with a range of 40 miles), and California and other states have a zero-emission vehicle program, likely to be strengthened in 2010, that requires automakers to supply increasing numbers of advanced vehicles. In addition, many states are considering revenue-neutral "fee-bate" programs that impose large taxes on the sale of gas guzzlers and offer rebates for low-GHG, energy-efficient vehicles. Feebate programs that have been implemented in several European countries since 2007 have effectively shifted consumer purchases toward efficient, low-carbon vehicles.

On-Road Efficiency Improvements

Actual fuel consumption can be reduced without advanced propulsion technology. Large improvements in "on-road" fuel economy can result from improved vehicle maintenance, more efficient ancillary and accessory equipment, and technologies that encourage more energy-conscious "eco-driving" styles.

Improved vehicle maintenance practices, such as inflating tires to the proper level and making sure wheels are aligned and replacing oil and air filters regularly, can ensure that vehicles operate at their designed efficiency levels. Maintenance practices also include the use of low-friction engine oils and low rolling resistance tires. Another change that does not directly impact efficiency but does reduce GHG emissions is replacement of the conventional air conditioning refrigerant, hydrofluorocarbon (HFC)-134a, with lower global warming potential gases like HFC-152a.

Fuel consumption can be significantly reduced by providing more and better information on how driving style affects fuel economy. New vehicles can be equipped with dashboard instruments that provide instantaneous fuel consumption, efficient engine rpm ranges, shift indicator lights, and tire pressure.

On-road fuel consumption can also be reduced by improving equipment not directly related to fuel propulsion, and thus not measured in government fuel economy ratings. Examples include more efficient alternators, air conditioning systems, and ancillary engine systems, such as dual cooling circuits and electric water pumps.

Improvements in actual on-road efficiency depend on real-world conditions (e.g., road, weather, and traffic conditions; driving style; accessory use; etc.). Based on data from the European Conference of Ministers of Transport and International Energy Agency (ECMT and IEA, 2005), as analyzed in Lutsey (2008), such improvements can reduce fuel consumption by more than 10 percent.

System Transformations and Reduced Vehicle Use

For the time being, the greatest reductions in oil use and GHG emissions in the transport sector are likely to come from improved vehicle efficiency and low-carbon fuels. But system transformations could eventually be important. The history of transportation is filled with continuous innovations, most of them small and incremental but some that are cumulative and lead to restructuring and reorganization. For example, impressive transformations have been made in the freight sector in the past few decades. The container revolution, combined with the use of information technologies, has led to huge gains in efficiencies in transporting goods. An integrated, multi-modal freight system has evolved that is far more efficient and less costly than the old system.

Improved maintenance practices, driver education, and ancillary equipment can reduce fuel consumption.

The same cannot be said, however, for surface passenger travel, which has not changed structurally for 80 years. Although, there are more limited-access expressways, and vehicles are safer and more comfortable, the structure, efficiency, and performance of the passenger transport system are largely unchanged. Cars, buses, and rail transit are still the dominant modes of transportation, and all of them have essentially the same functional performance.

Although some interest has been shown in automated highway lanes for cars and trucks using advanced control technologies and sensors, these efforts have faltered in the face of litigation and safety concerns. Information and communication technologies, referred to in the transportation community as intelligent transportation systems (ITS), have been embraced but have led to only incremental changes in current practices. Local governments have learned to use information to improve the management of road use, and travelers have gained access to navigational devices and information services that ease driving tension, reduce destination search times, and provide emergency services, but the net effect has been a very small decrease in driving and energy use.

Thus, there would seem to be opportunities for increasing fuel efficiency through system-level changes, if only because the current pattern of mostly single-occupant vehicle use is so inefficient. The answer, however, is not to expand conventional transit (e.g., full-size buses and rail transport). Today, transit buses in the United States consume about the same amount of energy per passenger mile as light-duty vehicles, largely because of low average ridership (Davis et al., 2008). Rail transit is somewhat better in terms of energy use per passenger mile, but except for New York City and a few other densely populated cities that have heavy ridership during both peak and non-peak hours, transit rail is also characterized by light use for much of the day, which translates to high average energy use per rider.

The net improvement from replacing personal vehicles with a suite of mobility services is likely to be substantial.

Clearly, increased load with existing service would result in less energy-intensive travel, but unless there are dramatic changes in land use or dramatic increases in the cost of owning and operating a car, these changes are unlikely. The run-up in gasoline prices in 2007–2008, followed by an economic downturn, did increase annual public transportation ridership by 4 percent, putting transit trips in 2007 and 2008 at a 50-year high (APTA, 2009). Despite these shifts, the aggregate effect of transit is still trivial in terms of reducing overall energy use (Davis et al., 2008).

If, however, ITS and other advanced technologies were used to create new mobility services, and were combined with changes in land use, broader system changes with much larger energy and GHG benefits might be achieved. One can imagine, for example, demand-responsive jitney services that pick up passengers at their homes or offices with only a few minutes notice, dynamic ride-sharing that facilitates carpooling among people with similar origins and destinations (e.g., commuting to the same office or traveling to a sporting event), and smart car-sharing that provides easy access to a variety of vehicles, all combined with more rational management of land use and the expanded use of conventional and bus rapid transit along high-density travel corridors. Such a transport system might provide higher quality service at lower cost for many individuals.

The key to substantial improvements in efficiency is replacement by households of one or more cars—which now cost more than $8,000 per vehicle per year to own and operate. The net improvement (and reduction in carbon footprint) resulting from the replacement of personal vehicles with a suite of mobility services has not been carefully modeled, but is likely to be substantial. The potential benefits would include less energy use and lower GHG emissions, as well as lower cost, less stress, and greater satisfaction. For many people, the combination of being freed of the stress and time demands of driving and having access to convenient services and nearby car-sharing might be more practical than owning and driving a vehicle.

Although a shift toward dense urban corridors would be at odds with long-term trends, changes in individual preferences (e.g., interest in urban amenities), values (e.g., environmental concerns), and costs of vehicle ownership and operation, might encourage change. For this kind of diversified system to evolve, however, there have to be changes not only in people's preferences, but also in policies and institutions that govern land-use management and the provision of transportation services.

Conclusions

Many transportation strategies for reducing energy use and GHG emissions are highly cost effective. When future energy savings are calculated using normal discount factors, improved gasoline and diesel vehicles have the potential to generate cost savings over the lifetime of the energy-saving technology or product. The use of alternative-fuel technologies could lead to far greater efficiency gains while also decoupling passenger transportation from petroleum use. When the full range of benefits, including improved energy security, reduced traffic congestion, and climate change are taken into account, many vehicle-efficiency and GHG-mitigation options seem even more attractive.

Nevertheless, there are considerable barriers to widespread deployment of efficient, low-carbon technologies and practices. Vehicle consumers, in the absence of automotive fuel and climate policies, have historically opted for larger vehicles, more sophisticated accessories, and more rapid acceleration. High fuel prices have led to increased sales of smaller and more efficient vehicles, but only temporarily. Unless policies, behavior, and market circumstances change, efficiency improvements will be implemented slowly.

A number of aggressive policies are under serious consideration, and some are being put into effect. Vehicle GHG standards that require substantial improvements in fuel economy (and greater use of efficient electric-drive vehicles) may also be adopted shortly in many states, and perhaps nationally. Zero-emission vehicle requirements in some states will provide an additional boost, as will low-carbon fuel standards, which have been adopted in California and in more limited form in the European Union and are under serious consideration in other states and at the federal level.

Financial enticements, such as feebates, tax credits for advanced vehicles, and higher fuel prices (e.g., prices resulting from carbon cap-and-trade programs), could provide a further boost by encouraging consumers to embrace more efficient vehicles and by encouraging technology companies to accelerate investment in advanced technologies. The combined effect of these policies would accelerate the development and use of energy-efficient, low-GHG vehicles and transportation systems.

References

APTA (American Public Transportation Association). 2009. Transit News. Available online at *http://www.apta.com/media/releases/090309_ridership.cfm*. March 9. Accessed April 14.

An, F., and J. DeCicco. 2007. Trends in Technical Efficiency Trade-Offs for the U.S. Light Vehicle Fleet. Society of Automotive Engineers Technical Paper Series. No. 2007-01-1325. April. Warrendale, Pa.: Society of Automotive Engineers.

Bandivadekar, A., K. Bodek, L. Cheah, C. Evans, T. Groode, J. Heywood, E. Kasseris, K. Kromer, and M. Weiss. 2008. On the Road in 2035: Reducing Transportation's Petroleum Consumption and GHG Emissions. Cambridge, Mass.: Laboratory for Energy and the Environment, Massachusetts Institute of Technology.

Davis, S.C., S.W. Diegel, and R.G. Boundy. 2008. Transportation Energy Data Book: Edition 27. ORNL-6981. Oak Ridge, Tenn.: Oak Ridge National Laboratory.

ECMT and IEA (European Conference of Ministers of Transport and International Energy Agency). 2005. Making Cars More Fuel Efficient: Technology for Real Improvements on the Road. Paris, France: Organisation for Economic Co-operation and Development.

EPA (Environmental Protection Agency). 2008. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2006. Washington, D.C.: EPA.

EPRI (Electric Power Research Institute). 2002. Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options for Compact Sedan and Sport Utility Vehicles. Final Report. Palo Alto, Calif.: EPRI.

Kalhammer, F.R., B.M. Kopf, D. Swan, V.P. Roan, and M.P. Walsh. 2007. Status and Prospects for Zero Emissions Vehicle Technology: Report of the ARB Independent Expert Panel. Sacramento, Calif.: State of California Air Resources Board.

Kromer, M.A., and J. B. Heywood. 2007. Electric Powertrains: Opportunities and Challenges in the U.S. Light-Duty Vehicle Fleet. Cambridge, Mass.: Laboratory for Energy and the Environment, Massachusetts Institute of Technology.

Lutsey, N. 2008. Prioritizing Climate Change Mitigation Alternatives: Comparing Transportation Technologies to Options in Other Sectors. Ph.D. Dissertation, UCD-ITS-RR-08-15. Institute of Transportation Studies, University of California, Davis.

Lutsey, N., and D. Sperling. 2005. Energy efficiency, fuel economy, and policy implications. Transportation Research Record 1941: 8–25.

Lutsey, N., and D. Sperling. 2009. Greenhouse gas mitigation supply curve for the United States for transport versus other sectors. Transportation Research Part D 14: 222–229.

NRC (National Research Council). 2006. State and Federal Standards for Mobile-Sources Emissions. Washington, D.C.: National Academies Press.

NRC. 2008. Transitions to Alternative Transportation Technologies—A Focus on Hydrogen. Washington, D.C.: National Academies Press.

NRC. 2009. Energy Efficiency in Transportation. Chapter 2 in Energy Efficiency Technologies: Opportunities, Risks, and Tradeoffs. Washington, D.C.: National Academies Press.

Bibliography

APTA (American Public Transportation Association). 2008. 2008 Public Transportation Fact Book, 59th ed. Washington, D.C.: APTA.

Ewing, R., K. Bartholomew, S. Winkelman, J. Walters, and D. Chen. 2007. Growing Cooler: The Evidence on Urban Development and Climate Change. Chicago, Ill.: Urban Land Institute.

Kahn Ribeiro, S., S. Kobayashi, M. Beuthe, J. Gasca, D. Greene, D.S. Lee, Y. Muromachi, P.J. Newton, S. Plotkin, D. Sperling, R. Wit, and P.J. Zhou. 2007. Transport and Its Infrastructure. Pp. 323–385 in Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. New York: Cambridge University Press.

Kasseris, E., and J. Heywood. 2007. Comparative Analysis of Automotive Powertrain Choices for the Next 25 Years. SAE Technical Paper 2007-01-1605, SP-2091. Warrendale, Pa.: SAE.

Kromer, M., and J. Heywood. 2008. A Comparative Assessment of Electric Propulsion Systems in the 2030 U.S. Light-Duty Vehicle Fleet. SAE Technical Paper 2008-01-0459. Warrendale, Pa.: SAE.

NRC (National Research Council). 2002. Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards. Washington, D.C.: National Academy Press.

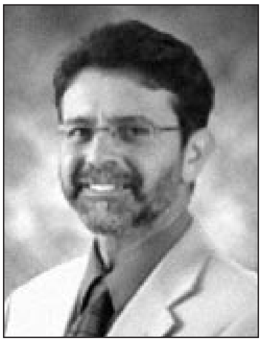
NRC. 2004. The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs. Washington, D.C.: National Academies Press.

NRC. 2008. Assessment of Technologies for Improving Light Duty Vehicle Fuel Economy: Letter Report. Washington, D.C.: National Academies Press. Available online at *http://www.nap.edu/catalog/12163.html*.

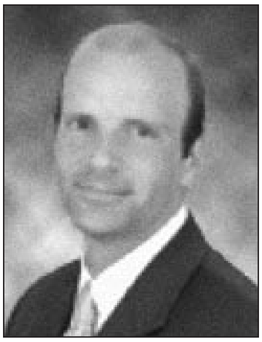
The challenge of the American Recovery and Reinvestment Act is to align policy, advance science, and educate consumers.

Building Materials, Energy Efficiency, and the American Recovery and Reinvestment Act[1]

Robin Roy and
Brandon Tinianov



Robin Roy



Brandon Tinianov

Historically, the phrases "building materials" and "rapidly advancing technology" have rarely appeared in the same sentence. In fact, many have argued that these terms are oxymoronic. Traditional gypsum drywall, for example, has not changed for more than a century, and changes in glass have been introduced only occasionally, and then very gradually, even though significant technology-driven improvements (e.g., low-emissivity [low-E] coatings and inert-gas fill) have been made.

Today, as everyone is looking for ways to make our country more energy efficient, we tend to overlook these ubiquitous building materials in favor of advanced technologies for, say, automobiles and electricity generation. However, if you take into account both building operations and materials manufacturing, the "built environment" is responsible for 52 percent of greenhouse gas emissions worldwide, far more than automobiles or

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Robin Roy is vice president of projects and policy for Serious Materials; he has been working for two decades to develop secure, economical, environmentally sound energy. Brandon Tinianov is chief technology officer at Serious Materials and a registered professional engineer; he has patents in construction materials that support global sustainability initiatives.

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[1] This article is based on testimony given before the U.S. House of Representatives Education and Labor Subcommittee on Workforce Protection on Green Jobs and their Role in our Economic Recovery, March 31, 2009. Original testimony available online at *http://edlabor.house.gov/documents/111/pdf/testimony/20090331RobinRoyTestimony.pdf.*

transportation in general (DOE, 2009). In fact, advancing the science of building materials will create opportunities for enormous energy savings and carbon reduction in the $1.3 trillion U.S. construction market.

The American Recovery and Reinvestment Act (ARRA) acknowledges this national priority with initiatives such as low-income weatherization, tax credits for energy improvements in private homes, energy refurbishment of public and assisted housing and schools, and energy improvements in local, state, and federal government buildings. The opportunity, and challenge, presented by ARRA is to align public policy, promote and support science, and educate consumers to maximize the benefits of these initiatives.

High-Performance Windows

Cost Benefits and Job Creation

According to Marc LaFrance, manager of the U.S. Department of Energy (DOE) Building Envelope and Windows R&D Programs, "Enhancing window efficiency is a major step forward in achieving net-zero homes. . . . Windows in the United States are costing consumers approximately $35 billion per year in energy. The next generation of windows could reduce this by more than half" (Serious Materials, 2008). In fact, energy lost through inefficient windows represents 30 percent of a building's heating and cooling energy, signifying an annual impact of 4.1 quadrillion BTUs (quads) of primary energy (Arasteh et al., 2006). Our research, using nationally recognized building-energy simulation models (e.g., RESFEN 5.0 [LBNL, 2009b]) shows that we can solve this problem today with highly insulating windows that can reduce heating and cooling costs by as much as 50 percent (Serious Materials, 2009).

Current strategies for reducing heat loss through windows involve a combination of technologies acting in harmony. The first and most common approach is the dual-pane, insulated-glass unit in which one or both glass panes have a unique, low-E coating to reflect infrared energy. The space between the glass panes is often filled with an inert gas (e.g., argon or krypton) to improve performance. More advanced systems have triple or quadruple glazing (with the additional central layers suspended) and low-E coated films. These designs can double or even triple the thermal performance of the window.

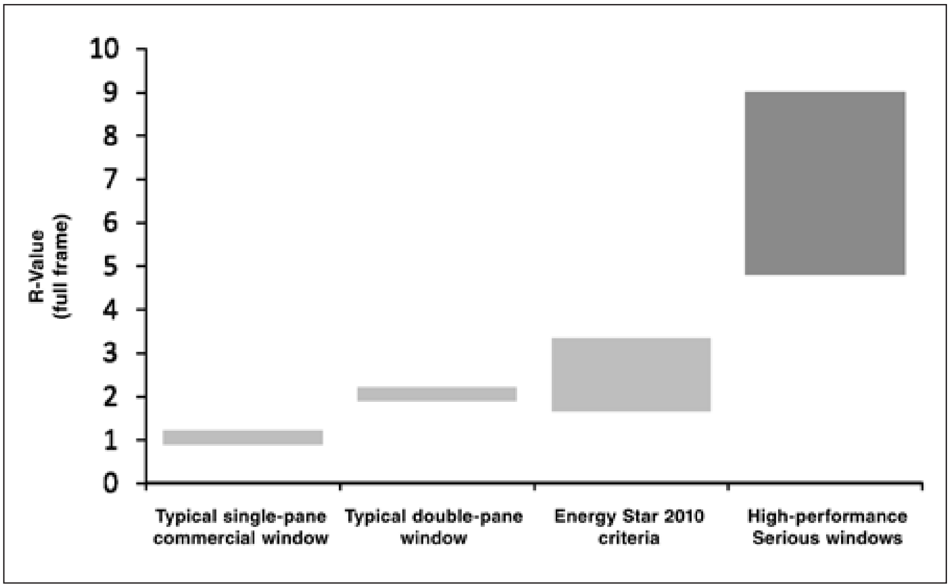

Figure 1 Comparison of full frame R-values for various window technologies.

For the entire window to achieve the performance of the insulated, multipane glass unit, today's state-of-the-art designs also have non-conductive spacers, redundant gas-retention systems, and foam-filled, airtight window frames. Taken together, these design elements can produce a window with an overall performance of R-5 to R-7 (a measure of thermal resistance used in the building and construction industry; the larger the number, the more effective the building insulation). The R value of most currently installed single-paned windows is R-1.2. Figure 1 shows comparative R-values for windows.

Advanced technology can not only deliver high performance, but can also lower product costs. In the past, window replacement or retrofits were often not cost-effective because of the poor performance and high cost of the new windows. However, with highly insulating, low-cost window technology, replacements and retrofits can be cost effective in many situations, including in public buildings and low-income weatherization programs.

One of the main goals of ARRA is to create jobs while simultaneously transitioning toward a more sustainable U.S. economy. Our company, for example, recently acquired and reopened two plants (one in Pennsylvania and one in Illinois) and hired back skilled manufacturing workers to produce energy-efficient windows.

The Adoption of New Technology

The adoption of a new technology is never a simple process. For example, based on "rules of thumb" and often outdated information about cost and/or performance, many energy-efficiency auditors, specifiers, engineers, and installers have been resistant to considering replacement windows and other new technologies. It has long been documented that many consumers and firms discount future savings from energy-efficiency investments at rates that go well beyond market rates for borrowing or saving. This pattern, often referred to as "the energy-efficiency gap," has been the subject of intense debate among energy-policy analysts for some time and is now a critical issue for climate-change policy.

The effective implementation of energy-efficiency measures through ARRA has the potential to accelerate the pace of change in the building industry, reduce greenhouse gas emissions, and make green building standards, such as Leadership in Energy and Environmental Design (LEED) and Energy Star, more meaningful. The effective implementation of ARRA can lead to a rapid expansion of operations for many businesses, the creation of jobs in new and previously existing plants, and the creation of jobs in upstream materials suppliers and installers of these new products. In addition, ARRA can create a win-win situation in which the creation of green jobs simultaneously helps to address climate change.

Overcoming Resistance to Change

To take advantage of the opportunities presented by ARRA, a number of administrative issues must be addressed. These are described below in the context of low-income weatherization, residential energy-efficiency tax credits, and school refurbishment. The descriptions are not intended to be comprehensive; they are examples of how resistance to change can be overcome.

Low-Income Weatherization

The low-income Weatherization Assistance Program (WAP), which has been operating for decades, supports cost-effective energy-efficiency measures by nonprofit "action agencies" across the country. However, because of low funding levels (e.g., about $200 million in 2008, supplemented by similar amounts from other government and utility programs), only about 100,000 households have been weatherized annually, a small fraction of the more than 15 million low-income households estimated by DOE to be eligible. ARRA provides an additional $5 billion in funding for WAP.

WAP has also been constrained historically by a cap on the maximum average investment per household, which meant that higher cost changes, even if they were shown to be cost effective, were not approved. ARRA addresses this problem by increasing the allowable investment from about $3,000 to about $8,000[1] for changes that are shown to be cost effective. This will allow for more complete weatherization and will provide much higher energy, environmental, and economic benefits for each household.

The "energy-efficiency gap" is now a subject of intense debate and a critical issue for climate-change policy.

Using Information Technology

Information technology (IT) can be used to help deliver the full potential of WAP. However, the software model (the National Energy Audit Tool [NEAT]) currently used by 34 states to assess the cost effectiveness of measures for households and to establish priorities is outdated and has severe shortcomings. For example, NEAT has a hardwired assumption that the best available replacement window has a thermal performance of R-2.2, far lower than the R-5 or higher performance readily available with current technology (Figure 2 and Table 1). In addition, NEAT does not use current state-of-the-art energy-analysis software, such as the Home Energy Saver software package sponsored by Lawrence Berkeley National Laboratory (LBNL, 2009a).

Using high-performance, full-frame R-value residential replacement windows would be an easy way to deliver on ARRA's midterm and longer term objectives of reducing heating and cooling costs and increasing both environmental performance and energy security. But for that to happen, a full-frame R-5 through R-11 window must be incorporated into the model.

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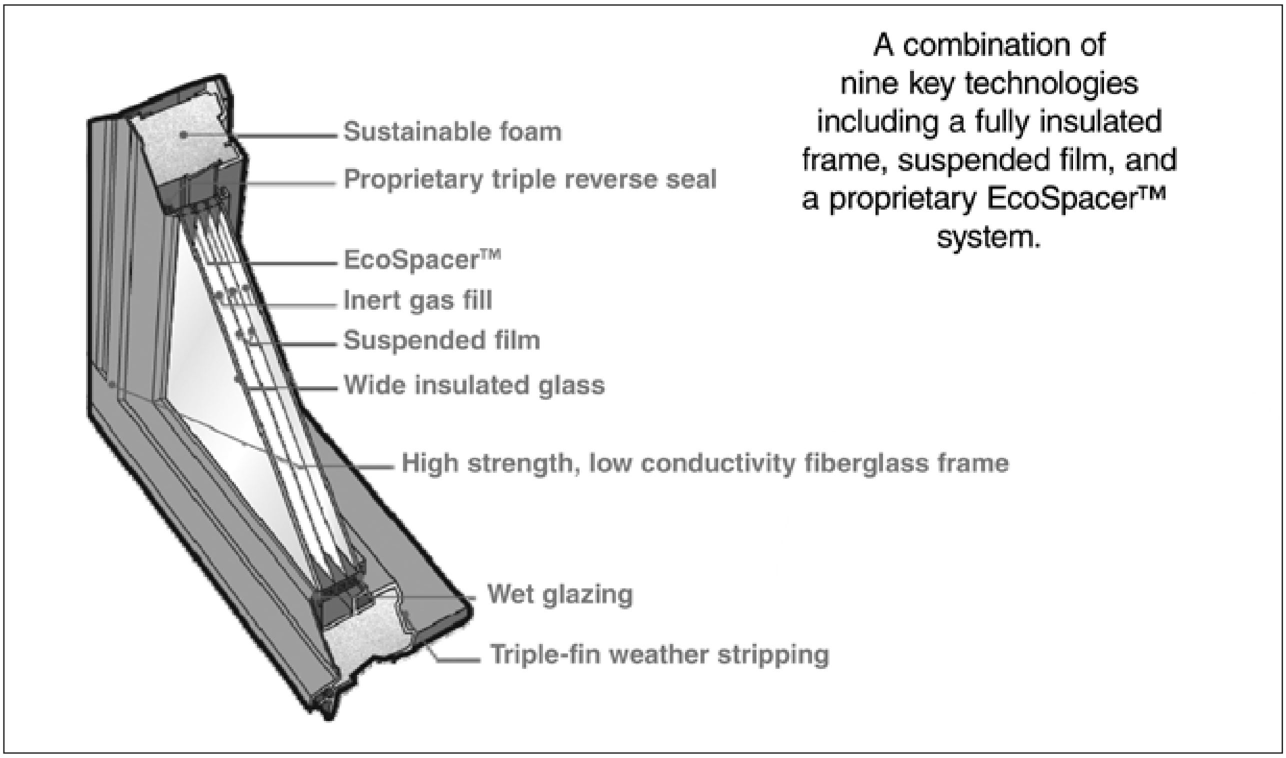
[1] This includes the inflation adjustment from the base year of 2000, as specified in 42 USC 6865.



A combination of nine key technologies including a fully insulated frame, suspended film, and a proprietary EcoSpacer™ system.

Figure 2 Cutaway drawing of the insulated glass unit (IGU) by Serious Materials.

TABLE 1 SeriousWindows IGU Technology Details

Key Technologies	Benefits
Sustainable foam	Sustainable foam insulation increases R-value over the full frame of the window.
Proprietary reverse triple seal	Reverse triple seal exceeds industry standards to increase longevity of the glass seal.
EcoSpacer™	Composite high-insulation spacer technology extends the high center of glass R-values to the edge of the frame.
Inert gas fill	Argon, krypton, or xenon gas strategically placed between the glass and suspended film maximizes R-value by suppressing conduction and convection within the glass unit.
Suspended film	Suspended film reduces convection and energy transfer without the weight and size of more glass. Suspended film systems are customized for thermal efficiency and maximum comfort. Suspended film systems offer up to 99.9% UV protection.
Wide insulated glass	Wide insulated glass results in better thermal insulation and higher STC (sound transmission class) ratings.
High strength, low conductivity fiberglass frame	Fiberglass frames, considered the "greenest" frames on the market, are very durable and provide excellent insulation.
Wet glazing	Wet glazing minimizes air leakage at the glass-to-sash bond, increasing R-value performance.
Triple-fin weather stripping	Triple-fin weather stripping substantially reduces air leakage and ensures high-energy performance.

We have been encouraging government agencies and their partners in the national laboratories to develop a modern Web-based application that can be made available quickly to enable models to include the latest available building technologies. In addition to delivering more accurate pre-weatherization energy and economic analyses, a Web-based software application would also provide better post-weatherization tracking and reporting of the overall program accomplishments and costs.

Residential Energy-Efficiency Tax Credits

ARRA increases the residential energy-efficiency tax credit to 30 percent of the first $5,000 spent on eligible products, including windows and doors, up to a limit of $1,500. In addition, it tightens the performance standards for eligibility for a range of products. To qualify to receive the tax credit, windows, for example, must have a U-factor of 0.30 or lower and a solar heat-gain coefficient of 0.30 or lower. Products that meet these performance standards, which can be readily achieved by using existing technology, are already available from several manufacturers. The higher standards will also encourage innovation by clearly rewarding better-performing products.

This will only happen, however, with continued support for high standards. Legislation has been introduced to roll back the performance criteria, and some have suggested referencing Energy Star criteria (R-2.8, U-0.35) instead of ARRA requirements. In our view, this would result in taxpayer dollars being wasted on unnecessarily inefficient products and would discourage innovation. Before tax credits can be based on Energy Star criteria, those criteria will require significant changes.

DOE has recently revised the Energy Star criteria for windows in the first part of a two-phase process. Phase 1 was urgently needed to catch up to code requirements that already exist in many states. Phase 2 would rework Energy Star standards and restore its leadership position. However, under current plans, discussions on Phase 2 will not begin until August 2009, with implementation at an unspecified future date.

The debate about how much to raise Energy Star requirements is ongoing. Many products being manufactured today, by us and others, already meet previously proposed (but not adopted) Energy Star requirements that will not take effect until 2013. We believe that if the criteria were made significantly more stringent, companies whose current products meet the relatively weak Energy Star requirements but do not qualify under ARRA for a tax credit would immediately begin to improve and innovate to meet the new criteria.

During the latest DOE comment period on the tightening of Energy Star requirements, many urged that the requirements be increased slowly. DOE is conducting a follow-up analysis to address the issues raised by stakeholders and to consider the criteria approved for the 2009 International Energy Conservation Code (International Code Council, 2009) and the criteria set forth for the 2009–2010 ARRA tax credit.

School Refurbishment

ARRA does not provide funding specifically for the energy-efficiency refurbishment of schools. However, it does provide substantial financial support—$22 billion in tax-credit bonds (TCBs)—that can be used for school refurbishment and construction (IRS, 2009). In contrast to a direct grant, a TCB is a relatively novel and somewhat unwieldy financial instrument. To demonstrate how TCBs work, we have been working with a few school districts and state and local governments to support school refurbishment and construction programs. The results are expected to be high levels of energy and economic performance.

High standards will encourage improvements and innovation.

One Billion Tons

From pressure by students on college campuses to CEOs, green building is a fast-growing mandate. In 2008, 12 percent of commercial projects received LEED or equivalent green certification (accounting for 41 percent of commercial spending), and the percentage of LEED-certified projects is expected to at least double by 2013 (McGraw-Hill Construction, 2008). Energy-efficient practices are already required by many federal, state, and local authorities, as well as by industry leaders such as General Electric, Cushman & Wakefield, Adobe Systems, and Bank of America.

We believe that WAP and the other ARRA initiatives described above could reduce emissions by 1 billion tons per year, or about 3 percent of the world's emissions, by helping to lower energy consumption in the existing built environment. Thanks to ARRA, we have a once-in-a-lifetime opportunity to change our built environment by deploying new technologies. It will take some effort to ensure that ARRA funds are allocated and spent wisely. But if they are, we look forward to great increases in sustainability in the built environment and a significant contribution to addressing climate change.

References

Arasteh, D., S. Selkowitz, J. Apte, and M. LaFrance. 2006. Zero Energy Windows. In Proceedings of the 2006 ACEEE Summer Study on Energy Efficiency in Buildings. Pacific Grove, Calif. August 2006. LBNL-60049. Available online at *http://gaia.lbl.gov/btech/papers/60049.pdf*.

DOE (U.S. Department of Energy). 2009. Buildings Energy Data Book. Washington D.C.: DOE.

International Code Council. 2009. 2009 International Energy Conservation Code. Washington, D.C.: International Code Council.

IRS (Internal Revenue Service). 2009. Qualified School Construction Bond Allocations for 2009. Notice 2009-35. Washington, D.C.: IRS.

LBNL (Lawrence Berkeley National Laboratory). 2009a. Home Energy Saver Software. Berkeley, Calif.: LBNL.

LBNL. 2009b. RESFEN5.0 Modeling Software. Berkeley, Calif.: LBNL.

McGraw-Hill Construction. 2008. Green Outlook 2009: Trends Driving Change. Bedford, Mass.: McGraw-Hill.

Serious Materials. 2008. DOE, TVA Partners in Groundbreaking Energy Efficiency Project. Sunnyvale, Calif. Available online at *http://www.ornl.gov/info/press_releases/get_press_release.cfm?ReleaseNumber=mr20081121-00*.

Serious Materials. 2009. RESFEN Modeling Results v7. Sunnyvale, Calif.

New York's effective energy-efficiency policies respond to changes in the marketplace and changes in technology.

Coming of Age in New York

The Maturation of Energy Efficiency as a Resource

Paul A. DeCotis is deputy secretary for energy in the Office of the Governor, State of New York.

Paul A. DeCotis

The energy-efficiency industry is maturing. Firms that provide energy-efficiency products and services are becoming more common, and their business models require less government support to be profitable, and reductions in energy use brought about by improvements in energy efficiency are now widely recognized as real and measurable.

As a result, these reductions have become an energy resource that can be valued as a commodity, much like a unit of energy. This has allowed markets to value, and in some instances trade, reductions in energy use as an asset. New York's leadership and support for the development of technologies and services to improve energy efficiency date back to the 1970s. Today, four decades later, the energy-efficiency industry has come of age.

When deciding whether to purchase a unit of electricity or to invest in energy efficiency, consumers usually respond by purchasing the unit of electricity. Often, they are not even aware that they are making such a decision—they simply turn on the lights or set their thermostats. Lack of information is one reason consumers are prevented from making informed, rational decisions about energy use.

Consumers are often unaware of the economics of saving a unit of electricity and the associated economic and environmental benefits. The commodity cost of electricity in New York averages 8.2 cents per kilowatt-hour (kWh), while reducing one kilowatt-hour of electricity use costs 3.9 cents (Figure 1).

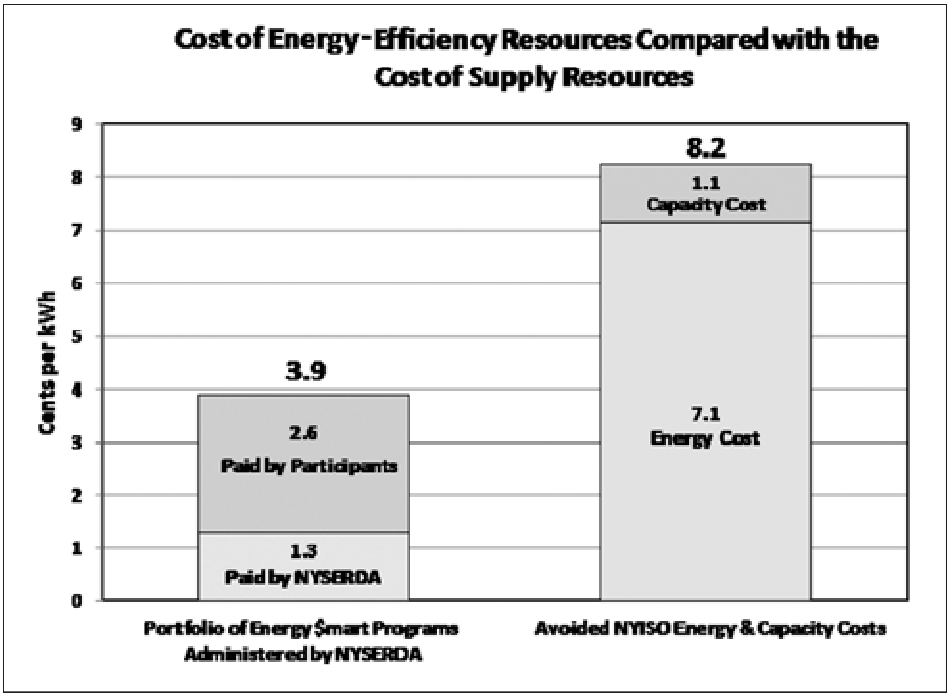


Figure 1 Energy-efficiency costs vs. generation. Source: NYSERDA.

Even consumers who are aware of the economics, however, may not take action to improve energy efficiency because of the intangible costs of efficiency measures, such as the time required and the perceived nuisance of the effort to change.

New York, like many other states and electric utilities, not only offers technical assistance, information, and financial incentives to consumers, but also keeps abreast of behavioral research as a basis for developing and implementing effective programs that encourage consumers to choose the investment in energy efficiency rather than purchasing the kilowatt-hour of electricity.

Government and utility intervention in markets has helped overcome many of the barriers preventing the widespread adoption and use of technologies that reduce electricity use and electricity demand. This is New York's story.

New York's Story

Since the late 1970s, New York has supported public and private investment in technologies and services to improve energy efficiency in all economic sectors. Significant inroads have been made, and these sectors now have technologies and processes that have improved energy efficiency. Policy makers and businesses have learned that reducing energy use is critical for reducing costs, stimulating economic growth, and postponing the need to build new and more costly power-generating facilities.

New York's energy-efficiency efforts include collecting a system-benefits charge (SBC) for supporting private investments in improvements in energy efficiency, continual updating of building-energy codes and appliance standards, and promulgating government directives that require state agencies to improve energy efficiency. New York also has a history of investing in research and development (R&D) programs that lead to the development, demonstration, and deployment of new technologies and industrial processes and ultimately to improvements in energy productivity. Working closely with utilities, the state energy authorities, including the New York State Energy Research and Development Authority, Power Authority of the State of New York, and Long Island Power Authority, have some of the most effective programs in the country for creating public-private partnerships to help consumers chose investments in energy efficiency over increased electricity use.

Although the past three decades have been characterized by growing population and greater demands for energy-using technologies to support rising lifestyle expectations, energy use per capita in New York has remained relatively flat—about one-third lower than the national average. New York's relatively low energy use per capita is due in part to its highly energy-efficient urban transportation system, which includes subways, commuter rail, buses, and ferries. It is also partly attributable to structural economic changes, such as a shift away from heavy industry toward a service and information-based economy.

Over the last five decades, as the value of financial and related services has increased as a share of gross state product (GSP), the share of industrial output has decreased. Despite the shift, however, industrial output increased an average of 2 percent annually; at the same time, overall energy use fell by 40 percent, and electricity use in the industrial sector remained flat. Thus, as industrial activity fell as a share of GSP, the industrial sector also became significantly less energy intensive and less electricity intensive, due in part to improved end-use energy efficiency.

Isolating precisely how much of the improvement in energy productivity is attributable to improved efficiency, as compared to the loss of energy-intensive industry in the state, is difficult because such data are not readily available. Nonetheless, a compelling case has been made that improved energy productivity is a significant contributing factor.

New York's electricity use per capita relative to use elsewhere in the United States provides an indicator of the overall success of New York's continuing efforts to promote the efficient use of electricity (Figure 2). Since 1960, New York's electricity use per capita has increased at a substantially lower rate than in the United States as a whole; the difference has increased from about 1,100 kWh to about 4,900 kWh. Note that California has also made impressive gains.

Table 1 shows the difference in electricity use per capita in New York and the country as a whole by major economic sectors. Residential use accounts for 41 percent of the difference; the industrial sector accounts for 53 percent of the difference. The commercial and transportation sectors account for the remaining 6 percent.

New York focused its efforts on end-use consumers to identify opportunities for energy savings and promote permanent changes in consumer behavior. Efforts targeting upstream market participants, including distributors, contractors, trade associations, and manufacturers, successfully induced structural changes that resulted in the accelerated adoption of energy-efficient technologies and practices. Because markets and consumer behaviors changed and government intervention was no longer necessary, several government-supported programs were discontinued. For example, once energy-efficient room air-conditioners had made significant inroads in stocking patterns by participating retailers and consumers were buying them at rates never seen before, financial incentives were reduced and ultimately eliminated—with little effect on stocking or purchasing behaviors.

Transitional Years

In the late 1970s, with federal funding provided through the newly created U.S. Department of Energy

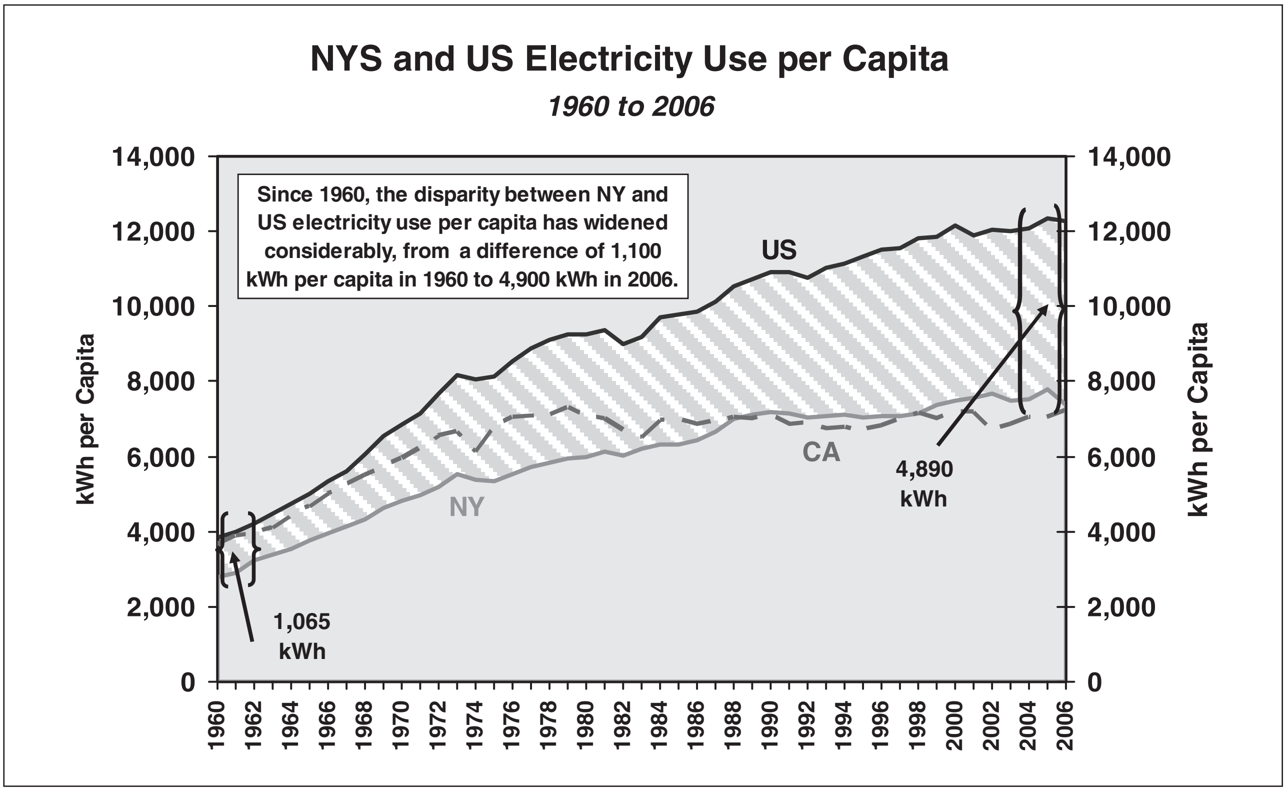


Figure 2 Per capita electricity use. Source: NYSERDA.

TABLE 1 Electricity Use by Sector

	Comparison of United States and New York per Capita Electricity Use in 2006			
	United States (kWh per person)	New York (kWh per person)	Difference (kWh per person)	Percentage of Difference
Residential	4,514	2,508	2,006	41
Commercial	4,341	3,938	403	8
Industrial	3,378	776	2,602	53
Transportation	25	145	–121	–2
Total	12,258	7,367	4,890	100

Source: NYSERDA.

State Energy Conservation Program (SECP), New York launched its first efforts directed toward improving energy efficiency and reducing the demand for electricity. Funding was limited, but the effort represented an important first step in focusing attention on the need for and benefits available from improving energy productivity. Over the years, the state was able to develop a portfolio of programs to address energy use in the residential, commercial, industrial, and institutional sectors.

The programs took another step forward in the 1980s when Congress appropriated funding to the states from a legal settlement against oil companies for charging excessive prices for crude oil in the late 1970s. By 1989, New York had received more than $335 million, including interest, from this funding source.

In 1984 New York's energy-efficiency efforts began in earnest, driven by construction delays and concerns about the completion of several large power plants. The state was convinced that reductions in demand were potential alternatives to continued investment in expensive power-generation projects. Utilities developed pilot demand-reduction programs funded at approximately $25 million annually statewide, representing approximately .0025 percent of gross annual utility revenues.

In 1987, New York concluded that demand-reduction programs were viable economic alternatives to new supplies of electricity and that they should be considered on an equal footing with supply in integrated resource planning. In the early 1990s, the state implemented a regulatory scheme that severed the relationship between electricity sales and revenues. Under this scheme, utilities would be made whole and all costs associated with their business would be covered, regardless of sales.

Along with this revenue-decoupling mechanism, the state approved financial incentives for achieving energy-efficiency goals, as well as financial penalties for falling short of those goals. The incentive scheme proved to be effective and was successfully adapted to each investor-owned utility.

By 1993, spending on reductions in demand and energy efficiency had reached $280 million. Additional spending by state energy authorities raised the annual investment in energy-efficiency resources to about $330 million.

In 1996, following a national trend, New York began the process of restructuring its electricity system to increase competition and reduce prices by requiring utilities to sell their power plants to independent power producers, thus creating a wholesale market for the buying and selling of electricity. Investor-owned utilities became transmission and distribution companies, and the responsibilities for administering energy-efficiency and demand-reduction programs were transferred to the New York State Energy Research and Development Authority (NYSERDA).

The role of utilities, following divestiture of generation assets, was to collect funds from ratepayers through an SBC to be used for administering energy-efficiency, demand-management, environmental-protection, and R&D programs. Since 1998, NYSERDA has been administering statewide programs funded by SBCs in cooperation with the Power Authority of the State of New York and the Long Island Power Authority.

In 2007, New York's investment in energy efficiency alone, excluding investment in R&D and renewable energy, was approximately $300 million (Figure 3). The amount was increased to close to $700 million in 2009 as part of an ongoing effort to significantly

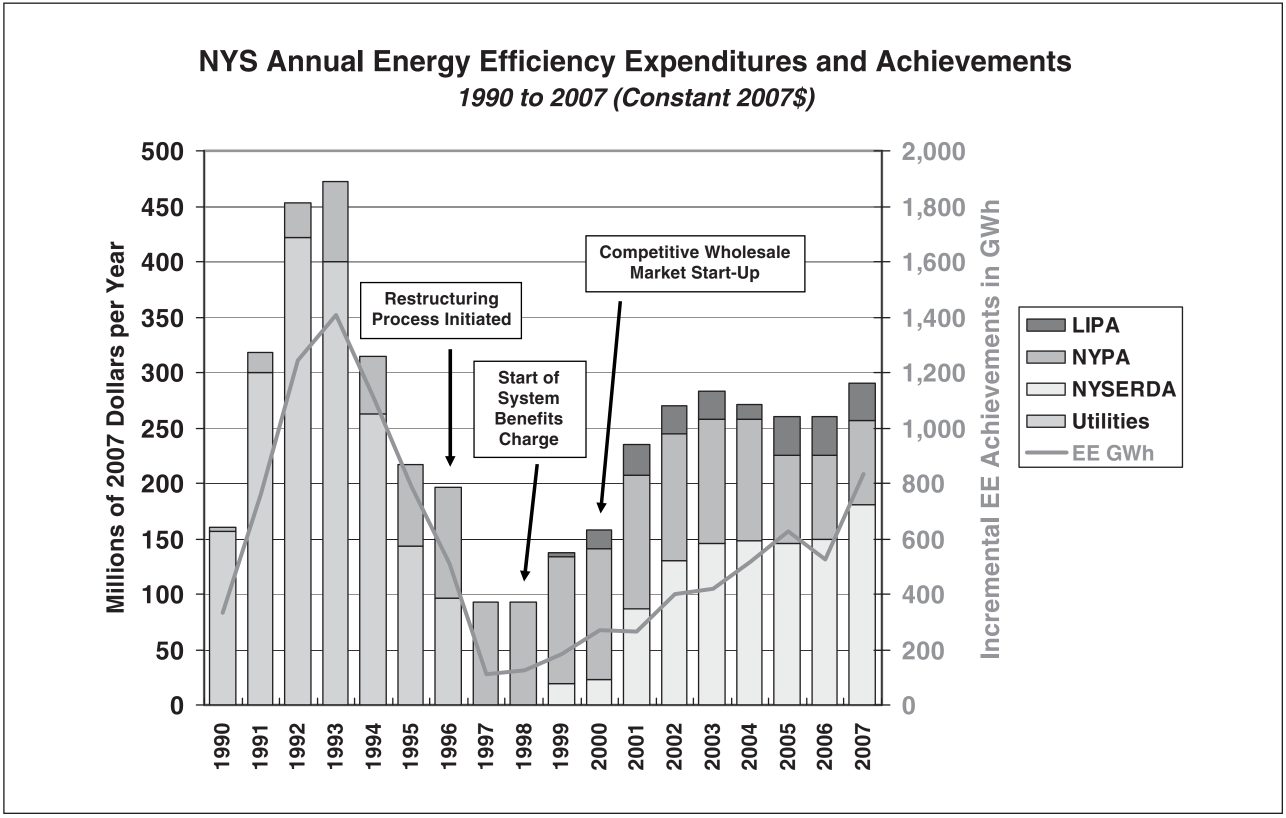


Figure 3 Energy-efficiency investments and achievements. Source: NYSERDA.

expand energy-efficiency programs.[1] Since 1990, New York has lowered its annual electricity use by nearly 12,000 gigawatt hours, or about 8 percent of end-use sales (Figure 4). The investment in energy efficiency and the savings achieved has created more than 18,000 net new jobs and reduced CO_2 emissions by about 6.5 million tons per year—equivalent to removing about 1.3 million cars from the roads annually.

By design, resource-acquisition and market-transformation strategies have led to substantial benefits beyond measured energy savings and reductions in peak demand. The programs have created highly skilled jobs, changed consumer attitudes and behaviors, expanded retail product offerings, and reinforced existing public policies. These "market effects" are expected to persist beyond the life of particular energy-efficiency programs and to continue to affect market dynamics and decision making by consumers. Market effects can be measured by analyzing the difference between total energy-efficiency market share realized in the presence of a program and the market share that can be directly attributed to the specific efforts of that program, as shown in Figure 4.

Through the end of 2007, the benefit-cost ratio, counting only direct utility-system benefits for New York's portfolio of SBC-funded energy-efficiency programs, is 6.2 (on a present value basis). Including non-energy benefits, such as improved comfort, safety, and productivity, the benefit-cost ratio increases to 9.9, and adding macroeconomic benefits (e.g., valuing increased employment) increases the ratio to 13.2. In

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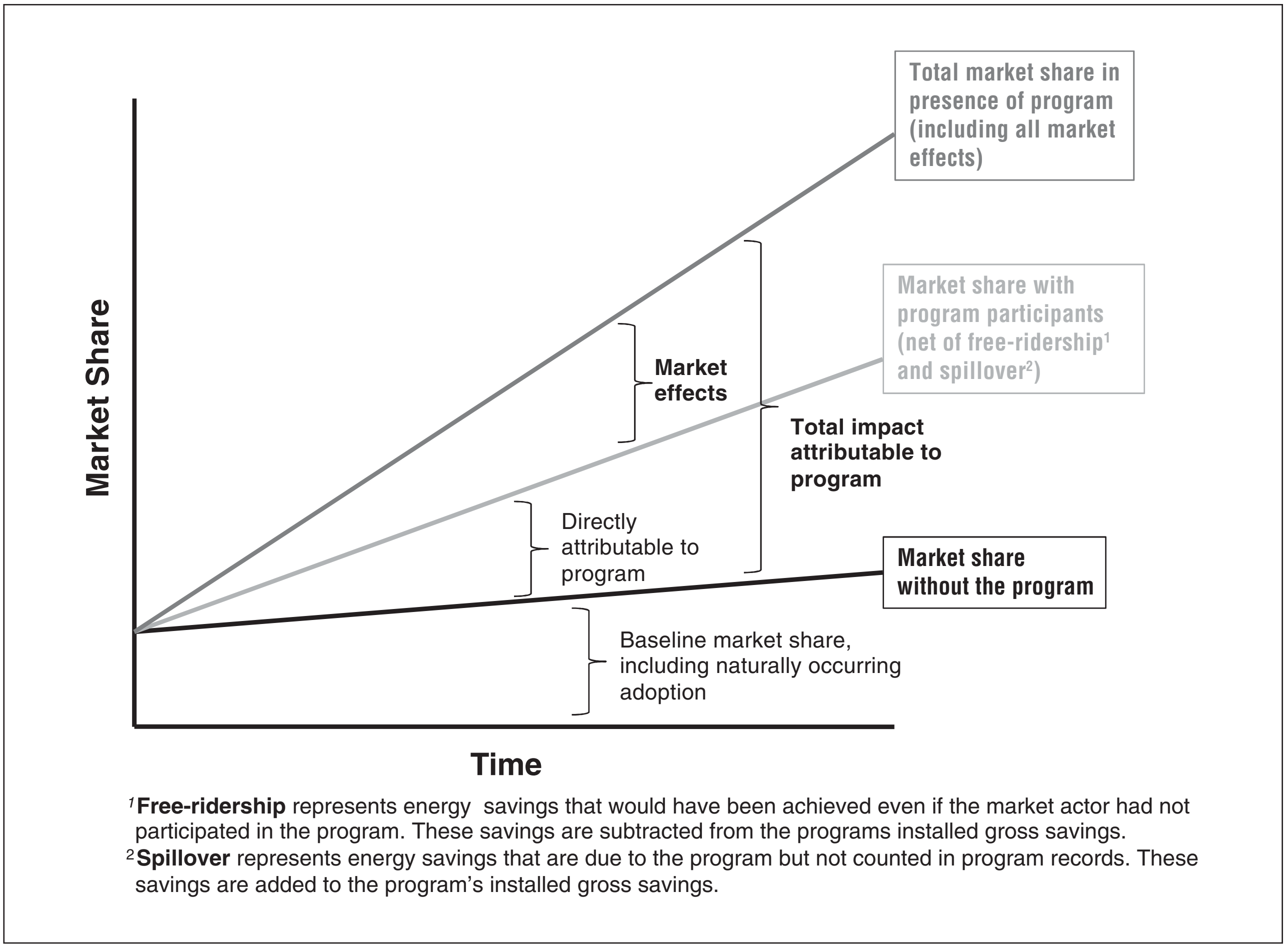
[1] New York's energy-efficiency programs are currently administered by the New York State Energy Research and Development Authority (NYSERDA), Long Island Power Authority (LIPA), and New York Power Authority (NYPA). To implement Governor Paterson's "15 by 15" energy-efficiency goal, the Public Service Commission is expanding NYSERDA's programs and reviewing new efficiency programs proposed by investor-owned utilities as part of its Energy Efficiency Portfolio Standard (EEPS) proceeding. Approved funding levels for efficiency programs as of this writing are: NYSERDA (System Benefits Charge): $175 million through 2011; LIPA: $924 million through 2019; NYPA (low-interest financing for energy services): up to $185 million per year; EEPS: $172 million per year through 2011. In addition to state-funded programs, the state Division of Housing and Community Renewal administers the Weatherization Assistance Program at a funding level of $68 to $100 million per year (before stimulus). NYSERDA will also administer the proceeds from the auction for the Regional Greenhouse Gas Initiative, which is expected to generate more than $500 million for clean-energy programs, including efficiency, over the next three years. See *http://www.dps.state.ny.us/Phase2_Case_07-M-0548.htm* for more information on EEPS.



[1] **Free-ridership** represents energy savings that would have been achieved even if the market actor had not participated in the program. These savings are subtracted from the programs installed gross savings.

[2] **Spillover** represents energy savings that are due to the program but not counted in program records. These savings are added to the program's installed gross savings.

Figure 4 Market effects. Source: NYSERDA.

2007 alone, customers realized net economic benefits of about $460 million as a result of SBC-funded efficiency programs implemented since late 1998.

Lessons Learned

Experience has demonstrated that well designed, well funded, and sustained public initiatives can result in substantial energy savings and that minimum efficiency standards can be a very effective strategy for stimulating improvements in energy efficiency on a large scale, especially if standards are updated periodically. Minimum efficiency standards have been a key element in both federal and state energy-efficiency efforts. To be effective, these standards must be technically and economically feasible and must provide enough lead time for manufacturers to phase out the production of nonqualifying products in an orderly way.

Government-funded R&D contributed to the commercialization of a number of important energy-efficiency technologies. Our experience has demonstrated that R&D can take many years to "pay off," and that in developing R&D programs, attention should be paid not only to technological advancement, but also to commercialization and market development. Although some evidence suggests that energy prices influence energy efficiency and levels of energy use, neither the federal government nor the states have used energy taxes as a strategy for stimulating greater energy efficiency to any significant degree.

The support of government policy and financial incentives can lead to the adoption of energy-efficiency measures. Financial incentives should be carefully designed to avoid costly efforts that have little or no incremental impact in the marketplace. One way to avoid this outcome is to provide incentives for newly commercialized technologies, particularly those with high initial cost but good prospects for cost reduction as demand grows, production expands, and learning occurs.

Education, training, and the dissemination of information can increase public awareness of energy-efficiency measures and improve know-how in energy management. The Energy Star labeling program exemplifies the impact of a well conceived, widely promoted labeling and education effort. Education and training are also important for the successful implementation of building-energy codes.

Energy-efficiency policies should be kept in place for a decade or more to ensure the orderly development of energy-efficiency markets. At the same time, policies such as efficiency standards and targets, product labeling, and financial incentives should be revised periodically. This will increase their effectiveness and reduce program costs (e.g., phasing out incentives as particular technologies become well established in the marketplace). In our experience, dynamic policies have led to steady improvement in the efficiency of residential appliances, while stagnant policies failed to maintain efficiency improvements in cars and light trucks during the 1990s and early years of this decade.

Energy-efficiency policies and programs have focused primarily on increasing the energy efficiency of buildings, appliances, vehicles, and industrial operations. Less attention has been paid to changing consumer behavior (e.g., encouraging people to drive less or buy fewer/smaller vehicles, appliances, or homes), although studies have shown that behavior modification has the potential to save 2 to 5 percent, without much difficulty. It remains to be seen how large a role behavior-modification programs can play in improving energy efficiency in the coming decades.

What Lies Ahead

Building on New York's history of investment in energy efficiency, in January 2009, Governor David A. Paterson announced a statewide "15 by 15" goal for New York, requiring that electricity use be reduced by 15 percent by 2015 (compared to what it would have been) and that 30 percent of the state's electricity needs be met by renewable resources. To meet this ambitious goal, New York is considering significantly expanding yet again its energy-efficiency programs. Achieving the "15 by 15" goal will require that electricity growth be completely offset through 2015, and in fact be slightly reduced.

Projections are that about 20 percent of the efficiency goal (i.e., about 3 of the 15 percent target) can be achieved by current programs. On the order of 40 percent of the goal (i.e., 6 of the 15 percent target) can be achieved through updates to the Energy Conservation Construction Code and appliance-efficiency standards (with most of the savings from appliance standards). The remaining 40 percent of the goal is likely to be met through a portfolio of new initiatives, including targeted energy-efficiency programs, market transformation, peak-demand management, and R&D on the commercialization of emerging technologies. New York is now looking into how it might integrate behavioral-change messaging and practices into its energy-services offerings as a catalyst to increase the return on traditional programs.

New York's successful energy-efficiency programs and initiatives have convinced many of the value of energy efficiency. These measures require no-risk investments by consumers who are slightly more proactive and willing to take steps to reduce their energy use and their carbon footprint. However, a new approach will be necessary for consumers who are content with the status quo, who have seen the facts and figures but are still resistant to change.

Government support of further growth in the energy-efficiency industry will be necessary until private investment in energy efficiency becomes second nature to everyone. Despite the increasing maturity of the energy-efficiency industry and the awareness that efficiency is a valued resource in energy-system planning, energy-efficiency policies will still be necessary to overcome market barriers. The key to their success is to design policies in a way that responds to changes in the marketplace as well as to changes in technology. These policies must include support for R&D to push the technological envelope, education for consumers through labeling, incentives for the most efficient products, and adjustments upward of minimum efficiency standards.

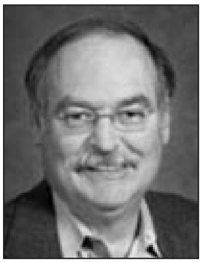
Note: All references are from materials either initiated by or gathered by the author for the New York State Energy Research and Development Authority to support the development of the 2009 State Energy Plan. The plan will be released in final form in October 2009.

China's remarkable history of energy savings has been inconsistent but effective overall.

The Greening of the Middle Kingdom:

The Story of Energy Efficiency in China

Mark D. Levine, Nan Zhou, and Lynn Price



Mark D. Levine

Nan Zhou

Lynn Price

The dominant image of China's energy system is of billowing smokestacks from the combustion of coal. More heavily dependent on coal than any other major country, China uses coal for about 70 percent of its energy (NBS, 2008). Furthermore, until recently, China had very few environmental controls on emissions from coal combustion; recent efforts to control sulfur dioxide emissions appear to be meeting with some success (Economy, 2007, 2009). Figure 1 shows the dominant use of coal in China's energy system from 1950 to 1980 (NBS, various years). However, this is just one side of China's energy story.

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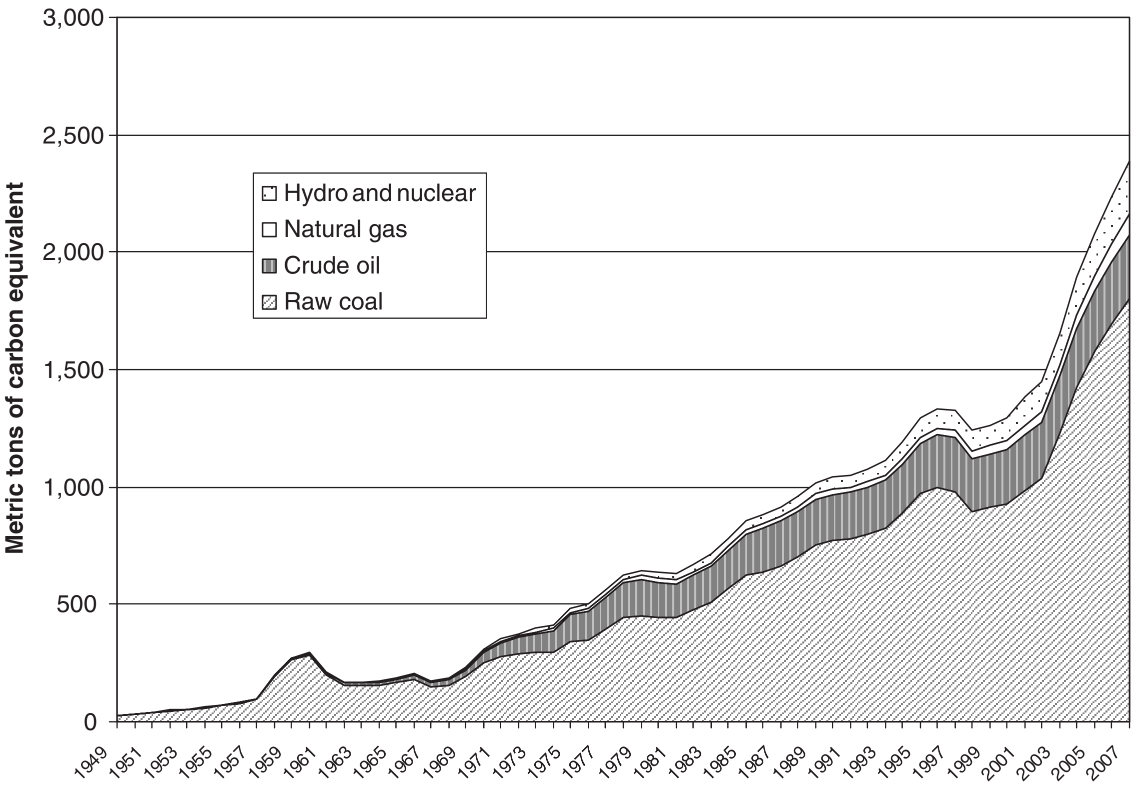

FIGURE 1 Coal dominates energy consumption in China. Source: NBS, various years.

Figure 2 illustrates the other side, and what may be the most important part of the story—China's energy system since 1980, shortly after Deng Xiaoping assumed full leadership. This figure compares the trends in energy consumption and gross domestic product (GDP) by indexing both values to 100 in 1980. The upper line shows what energy consumption in China would have been if it had grown at the same rate as GDP, since energy consumption usually increases in lockstep with GDP in an industrializing, developing country, at least until it reaches a high economic level.

The lower line in Figure 2 shows China's actual energy consumption, also indexed to 1980. The striking difference between the lines shows that GDP in China grew much faster than energy demand from 1980 to 2007, except during the 2002 to 2005 period when energy consumption grew much faster than GDP. Overall, by 2007 energy and energy-related carbon dioxide (CO_2) emissions were approximately 33 percent of what they would have been if energy and GDP had grown in tandem.

In this paper, we describe and assess three significant periods in China's remarkable energy history, beginning with a brief review of the three decades prior to 1980.

The Soviet Model: 1949 through 1980

From the beginning of the Communist regime in 1949 until the ascendancy of Deng Xiaoping in 1979, China's energy policy and the system it created followed the Soviet model—rapid increases in energy supply, low energy prices, centralized energy allocation to provide energy to heavy industry, and a disregard for environmental effects. The result of this policy was one of the fastest growing and least efficient energy systems in the world, on both the supply side and the demand side (Figure 3a).

The "Classic" Period of Energy Efficiency: 1980 through 2002

In 1980, in response to serious concerns in the academic community about Chinese energy policy, Deng Xiaoping adopted a strategy of reducing energy intensity.

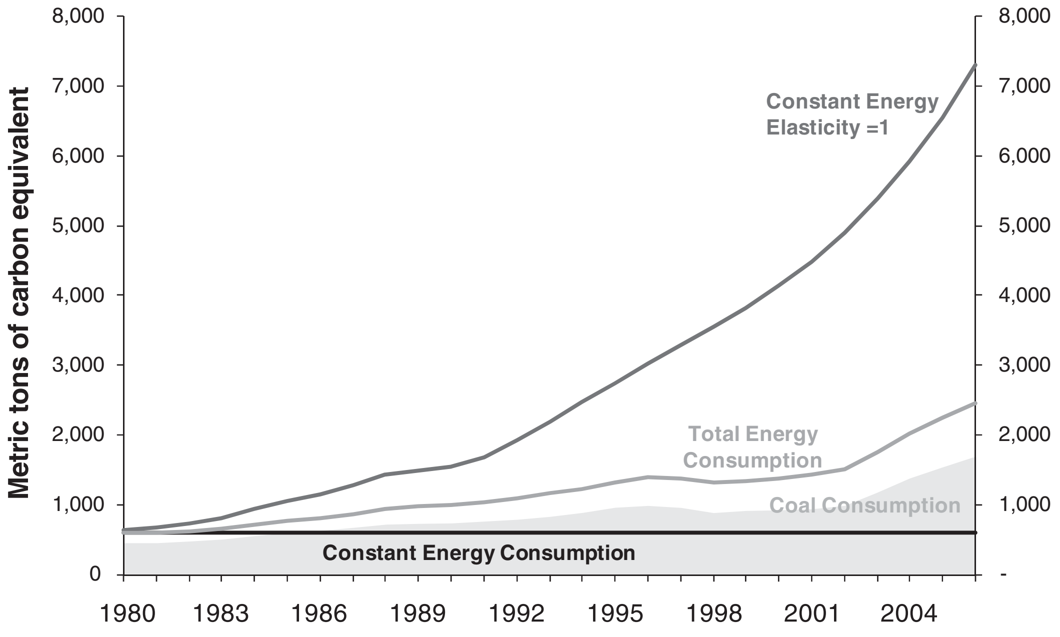

FIGURE 2 Actual energy demand in China is very much lower than energy demand at constant energy intensity, 1980–2006. Source: NBS, various years.

His stated goal was to quadruple GDP while only doubling energy consumption over a 20-year period, 1980 to 2000 (Lu, 1993).

China exceeded this goal both in the increase in GDP and the reduction of energy intensity (Figure 3b). This was achieved through a variety of innovative policies and programs, many of which were developed by the Chinese without significant knowledge of what other countries had done to promote energy efficiency. Not until a decade after China had embarked on its program to reduce the energy intensity of its entire economy did officials begin to establish ties with the energy-efficiency community outside its borders. Two of these policies—one on investment in energy efficiency and the other on establishing centers of expertise in energy efficiency throughout the nation—were far ahead of their time. To this day, no other country has implemented such policies as pervasively and effectively.

As shown in Figure 4, investment in energy efficiency accounted for more than 10 percent of total energy investment in 1981, the first year of Deng Xiaoping's program.[1] Investment later increased to 12 percent before slowly declining to a sustainable level of 5 to 6 percent.

In the early and mid-1980s, energy efficiency could be achieved inexpensively by fixing leaky pipes, inefficient boilers, and other equipment and by changing sloppy energy-management practices. Thus a 10 percent investment led to a much larger reduction in the increase in energy demand than a comparable investment led to increased energy supply. The investment program alone—which was just one of a number of energy-efficiency policies—achieved a significant portion of Deng Xiaoping's goals.[2]

The investment program spurred the development of new institutions, such as the China Energy Conservation Investment Corporation, which developed branches throughout the country to channel investments into energy efficiency and co-generation (strongly supported by the Chinese government). At the national level, the Chinese created the Bureau of Energy-Saving and Comprehensive Energy Utilization in the State Planning Commission (SPC). Today, after various restructurings, SPC has become the National

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[1] Data on investment in energy efficiency prior to 1981 are not available, but investments during these years were undoubtedly much smaller than the 10 percent figure of 1981.

[2] If one assumes a two-year payback on the investments in energy efficiency, then the investment level was sufficient to achieve more than half of the decrease in energy intensity sought by Deng.

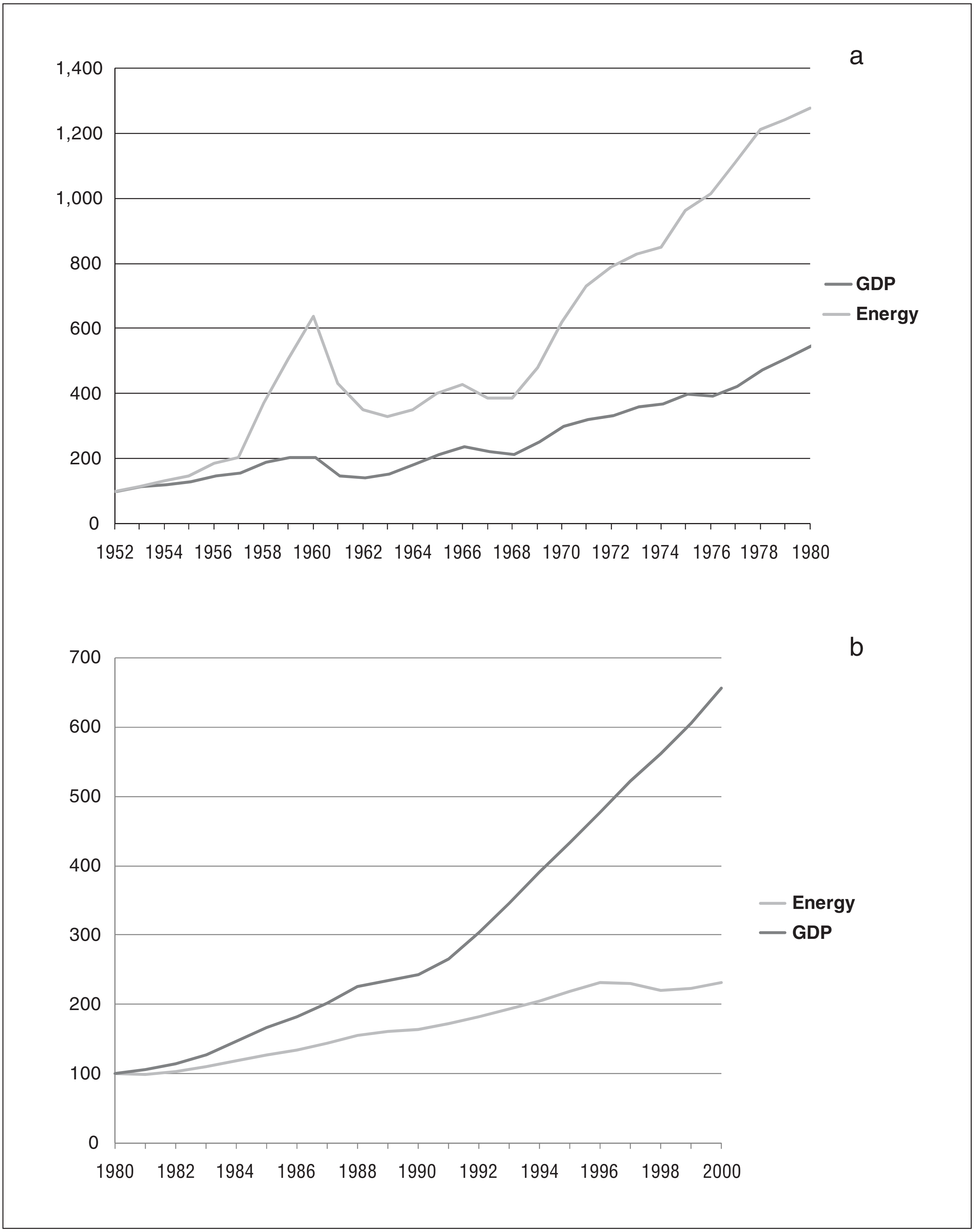

FIGURE 3 a. Energy demand grew twice as fast as GDP from 1952 to 1980. b. Energy demand grew 50 percent faster than GDP from 1952 to 1980, albeit from a very low level. Source: NBS, various years.

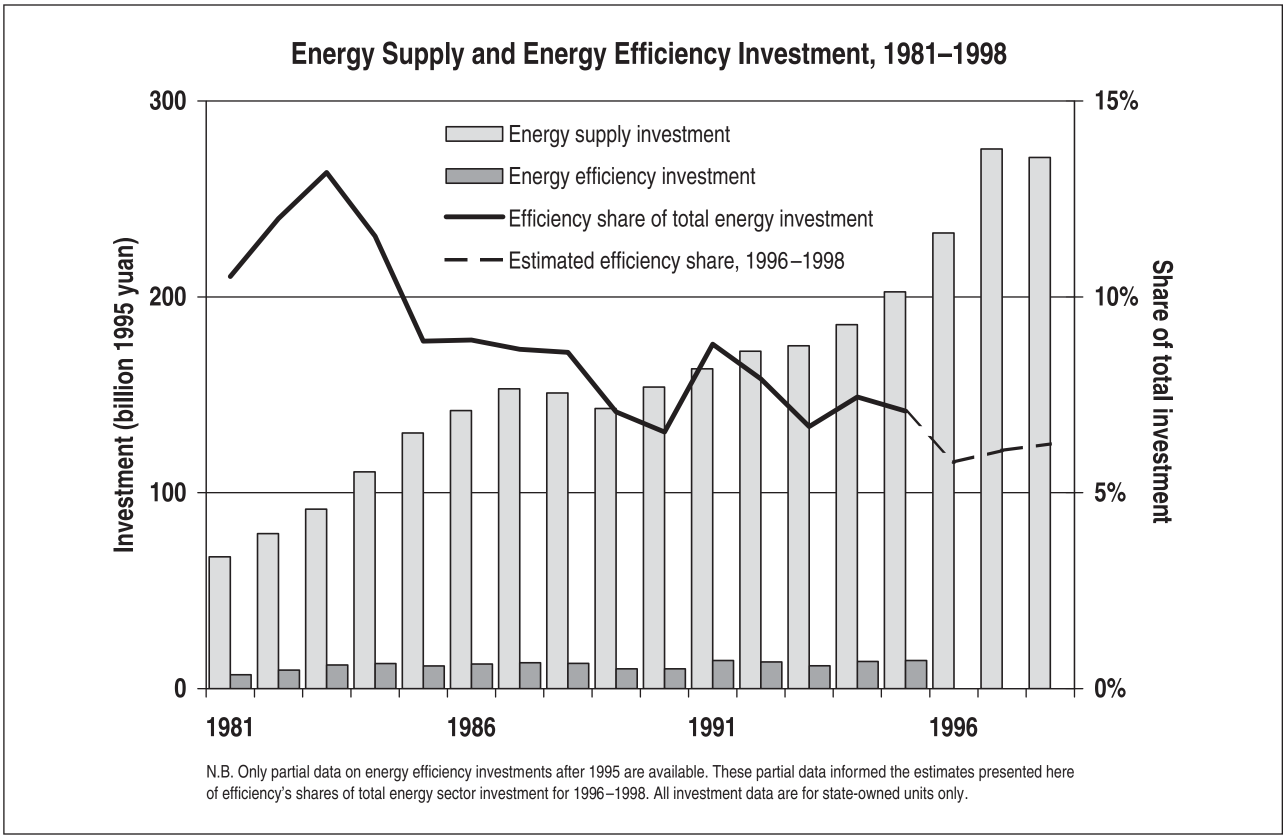

FIGURE 4 Investment in energy efficiency became a significant part of total energy investment in 1981. Source: NBS, various years.

Development and Reform Commission (NDRC). NDRC and its forerunner commissions are half a level above ministries in the Chinese hierarchy. All major requests to the State Council from ministries are supposed to—and often do—flow through NDRC. The very existence in the 1980s of a bureau for energy efficiency at this level indicates its importance.

This bureau created a variety of programs to promote energy conservation (a term for energy efficiency that is still often used in China). One of the most significant of these new policies was the establishment of energy-conservation service centers throughout the country. At their peak, there were more than 200 of these centers, employing more than 7,000 people across China. For a more complete description of institutional reforms to promote energy efficiency see Sinton and Levine (1998).

It is instructive to ask what might have happened if China had not embarked on such an aggressive and innovative policy. As Figure 2 shows, Chinese actions going back to 1980 enabled the country to avoid a situation in which global energy-related CO_2 emissions in 2007 would be three times higher than they are. This would have resulted in global emissions in 2007 at levels projected by the International Energy Agency for 2025 (IEA, 2008).[3]

Out-of-Control Growth in Energy Demand: 2002 through 2005

In spite of the slower increase in energy demand compared to GDP, there were signs in the late 1990s that energy efficiency was becoming less important to Chinese policy makers. Funding for government efforts to gather and analyze energy data was reduced significantly throughout the decade; as a result, data were not only less comprehensive, but also less accurate. China's system for gathering data on energy consumption, which had been one of the best among developing nations, was much weakened by the end of the 1990s. However, data on energy supply, which comes from a small number of energy-supply companies and are relatively easy to track, remained plentiful.

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[3] This is based on forecasted growth of energy-related CO_2 emissions by IEA (2008).

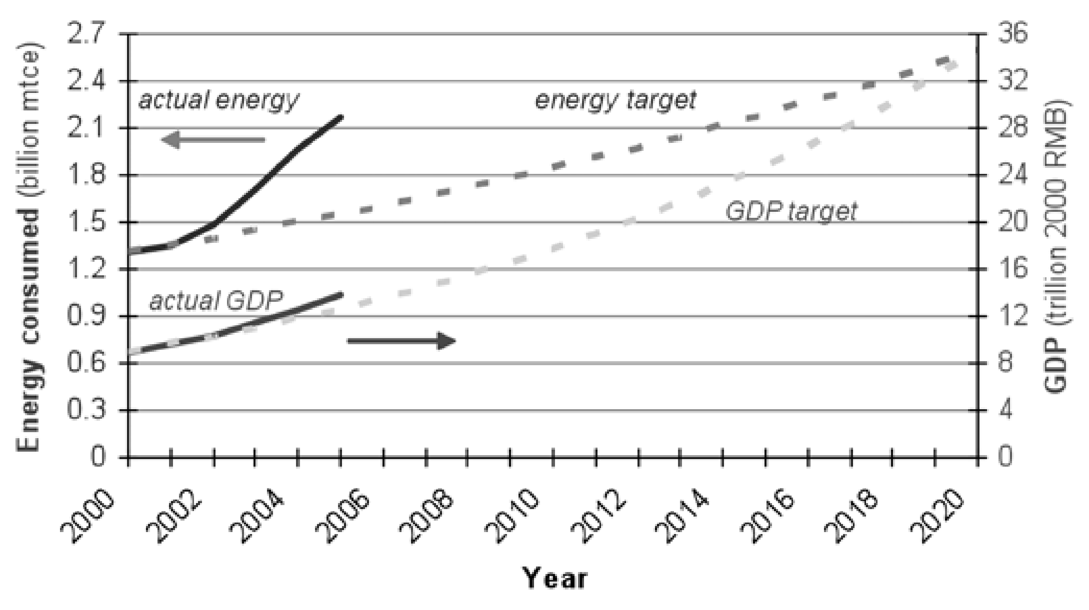

FIGURE 5 Beginning in 2002, increasing energy demand was on a trajectory to dramatically exceed the energy-reduction goals for 2020. Source: Lin et al., 2007.

By the turn of the century, little attention was paid to energy efficiency at the industrial-enterprise level, even though, by law, all key industries (i.e., industries that consume more than 10,000 metric tons of coal equivalent per year) were required to have an energy manager. By 2000, many large enterprises had energy managers in name only, if at all. This meant that the enterprises consuming the most energy had lost the expertise (and often the data) to assess and improve their energy efficiency.

Other signs that energy efficiency had a lower priority included the decline of many of the energy conservation centers; a dispirited bureaucracy in the bureau and division responsible for energy efficiency at the central government level; reduction in budgets for energy efficiency; and most important, the lack of authority and/or willingness in national, provincial, municipal, and local government bodies to enforce laws and regulations intended to save energy.[4]

At the same time the Chinese government lost its focus on energy efficiency, China's accession to the World Trade Organization (WTO) had the inadvertent effect of undermining more than two decades of efforts to reduce energy intensity. Beginning in the early 2000s, and coinciding with China's membership in WTO, there was a very rapid increase in exports, supported by rapid growth in industry to feed the export markets, which were heavily weighted toward energy-intensive products (i.e., products whose manufacture requires large amounts of energy and results in substantial CO_2 emissions) (Andrews-Speed, 2009).

In addition, China's internal demand for energy-intensive commodities like cement and steel to build infrastructure and cities to serve its rapidly urbanizing population outpaced the growth of less energy-intensive industries. This also contributed to the increase in overall energy use and energy-related CO_2 emissions.

These and other factors that contributed to the enormous output of energy-intensive industries in China resulted in energy demand that increased at breakneck speed and far exceeded the trajectory that would achieve the goal of quadrupling GDP while doubling energy demand from 2000 to 2020 (Figure 5). From 2002 to 2005, just three years, the construction of power plants increased to 100 gigawatts per year, and newly constructed plants had a capacity of more than 30 percent of total electricity-generation capacity in the United States.

Thus, as China developed its infrastructure, urbanized, and became the supplier of countless products to the world, its CO_2 emissions increased rapidly and dramatically. Clearly, this increase was partially due to demand in nations that imported products manufactured in

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[4] These statements are based on a large number of interviews by the lead author of this paper with government officials, researchers, industrialists, and academics during the 1990s and early 2000s.

China. But the commonly accepted system of accounting for greenhouse gas emissions (i.e., the convention used to assess compliance with the Kyoto Treaty of Annex I countries) attributes emissions to the country that produces products rather than to the country that imports them. Indeed, changing the attribution of greenhouse gas emissions from production to consumption would be difficult because of considerable uncertainties in assessing embodied energy in products.

In fact, in this three-year period, China's energy-related CO_2 emissions—which were 60 percent of those of the United States in 2002—approached the U.S. level by 2005 and surpassed it in 2006 (Figure 6). Previous forecasts as late as 2004 by Chinese government research institutes, international agencies, and mainstream analysts from various countries had predicted that China was unlikely to overtake the United States in energy-related CO_2 emissions until 2015, or even 2020 (Levine and Aden, 2008). However, development from 2002 to 2005 resulted in this wholly unexpected (and undesired) result for China.

How did this dramatic change come about, and what can the Chinese do about it? In brief, there were four major factors behind the dramatic rise in energy consumption in China:

- a gradual decline in the gathering of information on energy demand and in regulating demand by government institutions
- a rapid increase in the production of energy-intensive products for export as a result of China's membership in WTO
- increasing wealth and prosperity of a large portion of China (especially in the eastern provinces) and the associated construction of buildings and infrastructure, including transportation corridors (e.g., highways and canals for shipping freight and moving water) to serve this population
- ongoing rapid migration of people from rural areas, where they had consumed little energy, to urban areas, where energy consumption is much higher

One of the most dramatic indicators of this energy-intensive period is the increase in the production of cement. Figure 7 shows that China produces 50 percent of the cement produced worldwide (USGS, 2009). Although this is a startling statistic, it logically reflects the extraordinary pace of construction in China, which is a substantial portion of total worldwide construction.

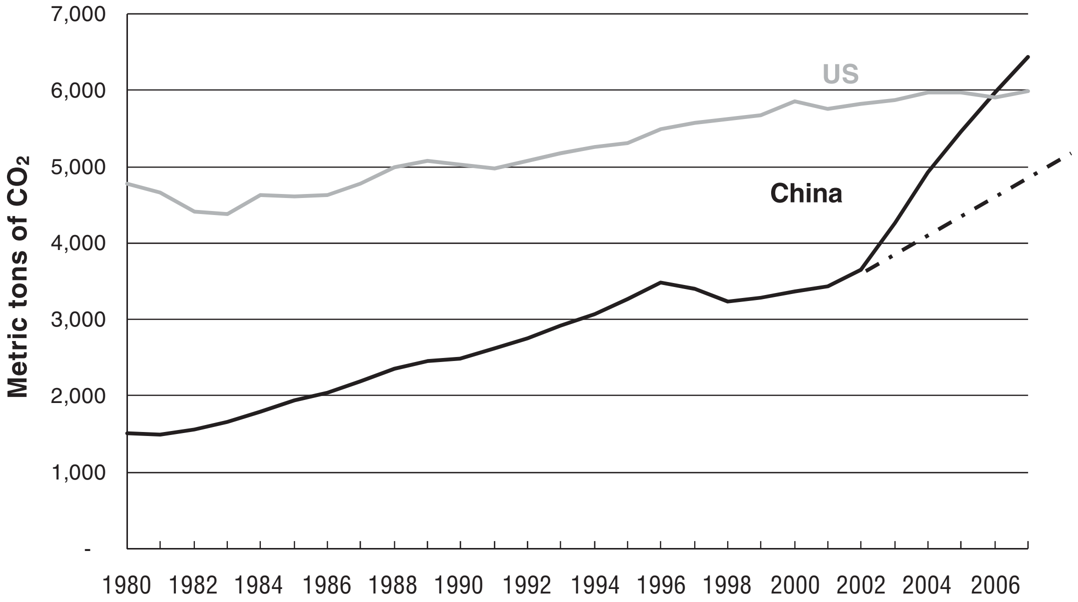

FIGURE 6 With the enormous increase in energy demand from 2002 to 2005, China became a larger emitter of energy-related CO_2 than the United States. Source: Levine and Aden, 2008.

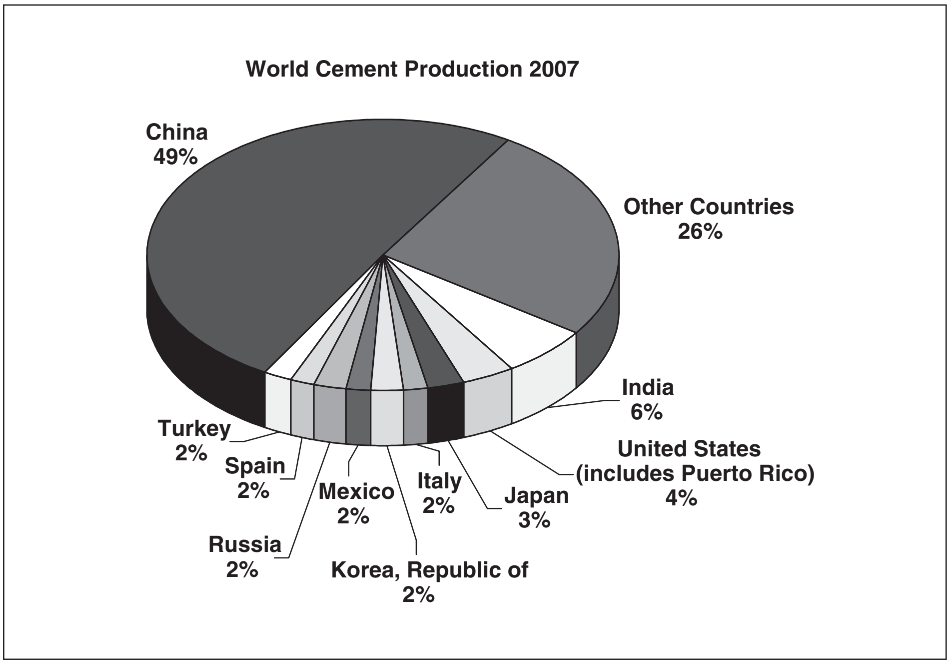

FIGURE 7 Cement production in China is 50 percent of world production. Source: USGS, 2009.

A Modern Re-enactment of the Early Days: 2005 to the Present

By 2005, officials at senior levels in the Chinese government had recognized that the rapid increase in energy demand presented serious problems and was unsustainable. The rate of construction of energy-supply infrastructure—hydroelectric facilities and power plants—was putting great pressure on China's industrial system and creating difficult problems with the safety and reliability of these complex systems.

As measured in investment cost per unit of industrial output, energy supply is one of the most capital-intensive industrial activities. Demand for capital to build new energy-supply and conversion systems necessarily competes with the demand for capital to promote balanced economic and social development. In addition, senior leaders of the Chinese government and party were becoming increasingly concerned about the negative environmental effects of the rapid increase in energy supply to meet burgeoning demand.

In November 2005, the Politburo issued a highly unusual statement setting a mandatory 20-percent reduction by 2010 in energy intensity (measured as energy consumption per RMB¥ of GDP).[5] The Politburo typically addresses broad issues and sets quantitative goals for the Chinese economy as a whole; setting goals for specific industry sectors is usually the purview of the government, rather than the party. Clearly, the Politburo's announcement of a 20-percent decrease in energy-intensity production indicated that the senior leaders perceived the energy problem to be extremely serious.

The level of activity that followed resembled the energy-efficiency initiatives of the early days that had led to the creative energy-conservation goals in the 6th Five-Year Plan and the intense activities that followed: legislation, regulations, government reorganization, and the creation of new institutions at the national, provincial, and municipal levels.

Nevertheless, there were important differences between the situation in 1980 and the situation in 2005. The economy in 2005 was approximately 10 times larger than in 1980 and was, therefore, much more difficult to manage. In 1980, most major energy-supply enterprises were government owned, while in 2005, although the government still exerted influence and retained some control over them, it did not own them.[6] The key difference, however, was on the demand side. By 2005, the government's ability to shape or restrain or, in many cases, even influence the demand for products, buildings, and services and the concomitant demand for energy services, was greatly limited.

In spite of these differences, the intensity and creativity of policy development for energy efficiency resembled the activity in China in the early 1980s, as well as the activity that followed the oil embargo in the United States and other industrialized countries. By 1975, three years after the embargo, many affected

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[5] RMB¥ is the Chinese currency, valued at 6.8RMB¥ per $U.S.

[6] Many of the energy-supply enterprises were still under the control of the state, either directly as state-owned enterprises or indirectly through the positions of their leaders in government (e.g., the heads of the national oil companies are officially government ministers, even though the companies are mostly privately owned).

TABLE 1 Recent Key Energy Policies Supporting China's 20-Percent Reduction Goal

Energy Policies	Date Effective	Responsible Agency
Fuel Consumption Limits for Passenger Cars	2004	
Medium and Long-Term Plan for Energy Conservation	2005	National Development and Reform Commission (NDRC)
Renewable Energy Law	2005	
Government Procurement Program	2005	NDRC and Ministry of Finance (MOF)
National Energy Efficient Design Standard for Public Buildings	2005	Ministry of Construction (MOC)
Eleventh Five-Year Plan	2006	NDRC
The State Council Decision on Strengthening Energy Conservation	2006	State Council
Reduced Export Tax Rebates for Many Low-Value-Added But High Energy-Consuming Products	2006	MOF
Top 1,000 Energy-Consuming Enterprise Program	2006	NDRC
"Green Purchasing" Program	2006	Ministry of Environment Protection (MEP) and MOF
Revision of Energy Conservation Law	2007	National People's Congress and NDRC
Allocation of Funding on Energy Efficiency and Pollution Abatement	2007	MOF and NDRC
China Energy Technology Policy Outline	2007	NDRC and the Ministry of Science and Technology
Government Procurement Program	2007	NDRC and MOF
National Phase III Vehicle Emission Standards	2007	
Interim Administrative Method for Incentive Funds for Heating and Metering and Energy Efficiency Retrofit for Existing Residential Buildings in China's Northern Heating Area	2007	MOF
Law on Corporate Income Tax (preferential tax treatment for investment in energy-saving and environmentally friendly projects and equipment)	2008	NDRC
Allocation of Funding on Energy Efficiency and Pollution Abatement	2008	MOF and NDRC
Appliances Standards and Labeling	Various Years	General Administration of Quality Supervision, Inspection, and Quarantine

countries had enacted and were enforcing a variety of laws and regulations requiring or promoting energy efficiency in automobiles, buildings, and industry. The United States, Japan, and major economies in Europe had created new institutions in both the public and private sectors to carry out these laws and regulations and, for the first time, had provided government funding to promote energy efficiency.

Table 1 summarizes some of the key laws, regulations, and programs put into place in China since the

Politburo directive of November 2005. These policies include the Top 1,000 Energy-Consuming Enterprises Program (Top 1,000 Program); the Ten Key Projects; allocations of government funds to support private investment in energy efficiency and pollution abatement; the creation of new government organizations and the strengthening of existing ones responsible for the design and implementation of energy-efficiency measures; and a variety of laws, regulations, and tax incentives.[7]

Many of these efforts are associated with the 11th Five-Year Plan, but some go well beyond it. Three of the most important policies are briefly described below.[8]

Ten Key Projects

In preparation for the intense focus on energy-efficiency policy that began with the November 2005 announcement by the Politburo, in 2004 NDRC initiated the "Ten Key Projects," and in 2005, the "Ten Key Projects" was incorporated into the 11th Five Year Plan. The four most significant of these projects are: the renovation of coal-fired industrial boilers; district-level combined heat and power projects; oil conservation and substitution; and energy efficiency and conservation in buildings. The expected impact of these four projects is a savings of up to 250 million metric tons carbon equivalent per year, about 40 percent of the 2010 target for energy intensity in China (NDRC, 2004).[9] Twenty provincial energy-conservation centers received financial support from the central government to assist in the implementation of these projects.[10]

Top 1,000 Energy-Consuming Enterprises Program

Launched in April 2006, the Top 1,000 Program was designed to improve industrial energy efficiency by targeting China's highest energy-consuming enterprises, which account for almost 50 percent of total industrial-sector energy consumption and 30 percent of total energy consumption in China. The Top 1,000 enterprises are in nine sectors: iron and steel, petroleum and petrochemicals, chemicals, electric power, nonferrous metals, coal mining, construction materials, textiles, and paper.

During the summer of 2006, all participating enterprises signed energy-conservation agreements with local governments committing themselves to reaching the energy-savings target by 2010. In addition, the energy-saving target was added to the provincial government cadre-evaluation system. Preliminary data indicate that the large majority of Top1,000 enterprises are meeting their interim targets (Price et al., 2009).

Four of the Ten Key Projects could save 250 million metric tons carbon equivalent per year.

Government Funding for Private Investment

In 2007, the Chinese government allocated 23.5B RMB¥ (about $3 billion at that time) to projects for improving energy efficiency and reducing pollution (MOF, 2008). This funding supported the launch of the Ten Key Projects (described above), the elimination of inefficient facilities, and the installation of measures to protect the environment. These funds are also being used to award 200 to 250 RMB¥ ($26 to $33) for every metric ton of coal equivalent an enterprise saves through the implementation of five of the Ten Key Projects in energy-intensive industries, coal-fired industrial boilers, district heating using cogeneration systems, and buildings (Jiang, 2006; Lu, 2006).

In 2008, the total allocation for energy conservation, emissions reduction, and ecological improvement was doubled to 42B RMB¥ (about $6 billion) (MOF, 2008). This funding includes 7.5B RMB¥ ($1 billion) for awards for the Ten Key Projects and 4B RMB¥ ($0.6 billion) for phasing out inefficient industrial plants.

Overall Results

In 2006, the energy intensity of the Chinese economy decreased by 1.7 percent, the first decrease in this

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[7] Another interesting policy is the responsibility system (also called the "one vote veto") in which a government official or manager of a state-owned enterprise cannot advance without meeting an energy-intensity target. Thus an individual may meet all of the criteria except the energy-intensity target with very high marks and still flunk the performance evaluation, with significant adverse consequences (Zhou et al., 2009).

[8] For a detailed review of energy-efficiency policies initiated during the 11th Five-Year Plan and after the announcement of the 20-percent intensity goal, see Lin et al., 2007.

[9] The other six have relatively small impacts.

[10] In 2006, financial support from the government for this purpose was ~64M RMB¥ (~$8 million). The United Nations Development Program/Global Environmental Facility added about ~8M RMB¥ ($1 million) to the total (Jiang, 2006). This is based on a currency conversion of $1 = 8.00419 RMB¥ (average rate of June 2006).

measure since 2001 (Zhou et al., 2009). Although this was a significant achievement, the reduction was well below the trajectory needed to achieve the goal of a 20-percent reduction by 2010. In 2007, however, energy intensity declined by 3.7 percent, and in 2008, it was reduced by 4.6 percent (Zhou et al., 2009). In the first quarter of 2009, preliminary data indicate an even greater reduction (China View, 2009).

Although the impact of the world economic crisis on energy intensity in China is difficult to predict, it now appears that China is likely to meet its 20-percent energy-intensity reduction target for 2010. These savings would represent a decrease of 1.5 billion metric tons of CO_2 (Lin et al., 2007), a very large number by any measure.

References

Andrews-Speed, P. 2009. China's on-going energy efficiency drive: origins, progress, and prospects. Energy Policy 37(4): 1331–1344.

China View. 2009. China's energy intensity down 2.9% in Q1: statistics office. Available online at *http://news.xinhuanet.com/english/2009-04/29/content*. April 29.

Economy, E.C. 2007. The Great Leap Backward. Foreign Affairs 86(5): 38–59.

Economy, E.C. 2009. Personal communication, May 4, 2009.

IEA (International Energy Agency). 2003. Energy Balances of non-OECD Countries. Paris: IEA.

IEA. 2008. World Energy Outlook. Paris: IEA.

Jiang, Y. 2006. Personal communication with Jiang Yun, China Energy Conservation Association, November 6, 2006.

Levine, M., and N. Aden. 2008. Global Carbon Emissions in the Coming Decades: The Case of China. Pp. 19–38 in Annual Review of Environment and Resources, Vol. 33. Palo Alto, Calif.: Annual Reviews.

Lin, J. 2005. Trends in Energy Efficiency Investments in China and the United States. LBNL-576921. Berkeley, Calif.: Lawrence Berkeley National Laboratory.

Lin, J., N. Zhou, M. Levine, and D. Fridley. 2007. Taking out 1 billion tons of CO_2: the magic of China's 11th Five-Year Plan? LBNL-62886. Berkeley, Calif.: Lawrence Berkeley National Laboratory.

Lu, Y. 1993. Fueling One Billion: An Insider's View. London, U.K.: Paragon Press.

Lu, X. 2006. Personal communication with Lu Xinming, director, Department of Environment and Resources Conservation, National Development and Reform Commission, September 9, 2006.

MOF (Ministry of Finance). 2008. Ministry of Finance sets aside 27 Billion RMB¥ for supporting energy saving and emission reduction. Available on line at *http://www.mof.gov.cn/caizhengbuzhuzhan/zhengwuxinxi/caizhengxinwen/200805/t20080519_29017.html*.

NBS (National Bureau of Statistics). 2008, and various years. China Statistical Yearbook. Beijing, China: China Statistics Press.

Price, L., W. Xuejun, and Y. Jiang. 2009. The challenge of reducing energy consumption of the top 1,000 largest industrial enterprises in China. Energy Policy (special issue). In press. Available online at *http://www.sciencedirect.com/science/article/B6V2W-4W329GD-1/2/a7612e71ef7f84b4cade01abbd34106b*.

Sinton, J., and M. Levine. 1998. Energy efficiency in China: accomplishments and challenges. Energy Policy 26(11): 813–829.

USGS (U.S. Geological Survey). 2009. Mineral Commodity Summaries: Cement. Washington, D.C.: USGS.

Zhou, N., M. Levine, and L. Price. 2009. Overview of Current Energy Efficiency Policies in China. Submitted to Energy Policy.

NAE News and Notes

NAE Newsmakers

Bernard Amadei, professor of civil engineering, Department of Civil, Environmental, and Archi-tectural Engineering, University of Colorado, and founder of Engineers Without Borders-USA, received the **2008 Award of Excellence** from *Engineering News Record* (ENR), the magazine's highest honor. Dr. Amadei was recognized as "an academic who is giving engineering education a new twist, founding a movement catching on with students, professionals and global communities." Dr. Amadei was the subject of a cover story in the March 30 issue of ENR.

Mark A. Barteau, senior vice provost for research and strategic initiatives, University of Delaware, is the recipient of the **2009 Giuseppe Parravano Award** from the Michigan Catalysis Society. The award was presented at the society's 31st annual spring symposium in May. Dr. Barteau was cited for "groundbreaking contributions to catalysis by metal oxides and transition metals, which led to the development of fundamental understanding and design of novel, improved catalytic materials."

James M. Duncan, University Distinguished Professor of Civil Engineering, Emeritus, Virginia Polytechnic Institute and State University, received the American Society of Civil Engineers (ASCE) **2009 Outstanding Projects and Leaders (OPAL) Lifetime Achievement Award for Education**. Dr. Duncan was selected for his extraordinary contributions to education since 1965. **Jeremy Isenberg**, senior principal, AECOM, was the recipient of the ASCE **2009 OPAL Lifetime Achievement Award for Design**. Both awards were presented during the annual ASCE OPAL Gala at the Hyatt Regency Crystal City in Arlington, Virginia.

Susan J. Eggers, Microsoft Professor of Computer Science and Engineering, Department of Computer Science and Engineering, University of Washington, is the recipient of the **2009–2010 Athena Lecturer Award** from the Association for Computing Machinery Committee on Women (ACM-W). The award includes a $10,000 honorarium provided by Google Inc. Dr. Eggers was honored for her work on computer architecture and experimental performance analysis, which led to the development of simultaneous multithreading, the first commercially viable multithreaded architecture.

Michael D. Griffin, chief operating officer, GriffinSpace LLC, received the **National Space Trophy**, the highest award given by Rotary National Award for Space Achievement. The award is presented annually to an individual who has furthered national goals in the field of space. The Honorable Michael Griffin was selected for developing the plan for completing the International Space Station following the loss of Space Shuttle Columbia; directing the shuttle return-to-flight activities; initiating the first procurement of commercial cargo and crew service; establishing the architecture for a sustainable, achievable, and technically viable human exploration program; and awarding the initial spacecraft and launch vehicle contracts.

David Japikse, chairman/CEO, Concepts NREC, is the recipient of the **Cliff Garrett Turbomachinery Engineering Award** from the Society of Automotive Engineers (SAE) International. Dr. Japikse was honored at the SAE 2009 World Congress Awards Ceremony held in Detroit in April. The Cliff Garrett Award, established in 1984, is given in recognition of an authority in turbomachinery engineering for on-highway, off-highway, spacecraft, or aircraft vehicle use. The award is funded by the Garrett Corporation, a division of Honeywell, through the SAE Foundation.

Pradman P. Kaul, president and CEO, Hughes Communications Inc., was inducted into the **Society of Satellite Professionals International (SSPI) Hall of Fame** on March 25, 2009, for "outstanding business and technology leadership in a long career with Hughes" and for his contributions to the development of "industry-changing, innovative technologies, such as the TDMA satellite communications system, VSAT technology, digital set-top boxes, and the Internet protocol over satellite (IPoS) standard . . . [which have] made possible the age of satellite communications."

Jeong H. Kim, president, Bell Labs, Alcatel-Lucent, is the recipient of the 2009 **Chinese Institute of Engineers (USA) Distinguished Lifetime Achievement Award**.

The award is giving in recognition of an Asian-American engineering professional with a record of significant personal achievements, and contributions to academia, public service, and industry. The Lifetime Achievement Award is conferred annually in conjunction with the celebration of National Engineers Week.

Barbara H. Liskov, Institute Professor, Massachusetts Institute of Technology, is the winner of the **2008 ACM A.M. Turing Award** presented by the Association for Computing Machinery. Dr. Liskov was cited for her foundational innovations to designing and building the pervasive computer system designs that power our daily lives. Her achievements in programming language design have become the basis of every important programming language since 1975. The Turing Award, widely considered the "Nobel Prize in Computing," includes a $250,000 prize, with financial support provided by Intel Corporation and Google Inc.

Ponisseril Somasundaran, director, NSF/IUCR Center for Surfactants, and La Von Duddleson Krumb Professor, Columbia University, was honored at the 2009 Society of Mining, Metallurgy, and Exploration (SME) Annual Meeting in February in Denver, Colorado, with a symposium, "Innovations in Minerals Research, Operations and Education for Sustainable Development," during which scientists from around the world presented papers on various aspects of sustainability. Professor Somasundaran was further honored with an award with the following citation: "On behalf of Dr. Ponisseril Somasundaran's colleagues and students, the Society for Mining, Metallurgy and Exploration presents this honor, in recognition of his life-long dedication and achievement in mineral process engineering and education of generations of the world's finest engineers."

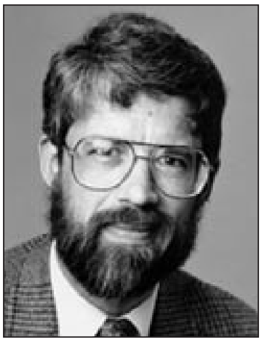
T.W. Fraser Russell, Allan P. Colburn Professor, Chemical Engineering, University of Delaware, has been selected to receive the **Lifetime Achievement in Chemical Engineering Pedagogical Scholarship Award** from the American Society for Engineering Education. The award is given to honor a "sustained career of pedagogical scholarship which not only caused innovative and substantial changes, but also inspired younger educators to new behaviors which benefit students in chemical engineering." Dr. Russell was cited for "an outstanding career in education . . . characterized by a close relationship with industry and a strong belief that one cannot effectively teach engineering without understanding the 'art' aspect of the profession."

Steven B. Sample, president, University of Southern California, received the **Asian Pacific Alumni Association President's Award** for his "visionary direction." The award was presented to Dr. Sample on April 17, 2009.

C.P. Wong, Regents' Professor of Materials Science and Engineering and Charles Smithgall Institute Endowed Chair, School of Materials Science and Engineering, Georgia Institute of Technology, received the **2008 Total Excellence in Electronics Manufacturing (TEEM) Award** from the Society of Manufacturing Engineers in recognition of his extraordinary dedication to setting new or higher standards of achievement in electronics manufacturing. Dr. Wong also received the **Best Conference Paper Award** for "Nano Materials for Electronic and Photonic Packaging." The awards were presented at the IEEE 7th PolyTronic Conference in Garmisch, Germany.

Wm A. Wulf, President Emeritus, National Academy of Engineering, and University Professor and AT&T Professor of Engineering and Applied Sciences, Department of Computer Science, University of Virginia, received the **Award for Distinguished Public Service** from IEEE-USA. Dr. Wulf was honored for advancing engineering professionalism and promoting U.S. competitiveness in science and technology.

Four NAE Members Appointed to President's Council of Advisors on Science and Technology



John Holdren

Shirley Ann Jackson

Maxine Savitz

Eric Schmidt

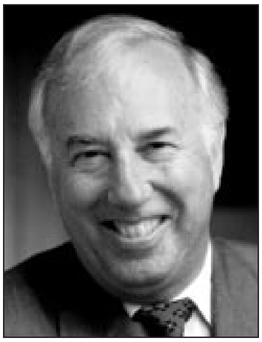
During President Barack Obama's remarks at the National Academy of Sciences Annual Meeting on April 27, 2009, he announced the appointments of four NAE members to the President's Council of Advisors on Science and Technology (PCAST). PCAST is a group of leading scientists and engineers chosen to advise the president and vice president and to formulate policy in areas that require an understanding of science, technology, and innovation. Part of the Executive Office of the President, PCAST is administered by the Office of Science and Technology Policy, which is headed by NAE member **John Holdren**.

PCAST was established in 1990 to ensure that the president receives advice from the private sector and the academic community on technology, research, and math and science education. "This council represents leaders from many scientific disciplines who will bring a diversity of experience and views," President Obama said. "I will charge PCAST with advising me about national strategies to nurture and sustain a culture of scientific innovation."

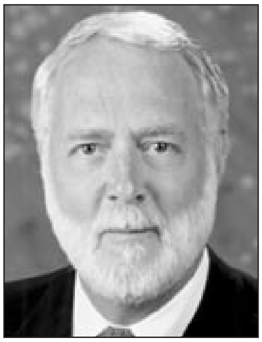
The newly appointed members of PCAST are: **John Holdren**, Teresa and John Heinz Professor of Environmental Policy, Belfer Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University; **Shirley Ann Jackson**, president, Rensselaer Polytechnic Institute; **Maxine Savitz**, vice president of NAE and retired general manager, Technology/Partnerships, Honeywell Inc.; and **Eric Schmidt**, chairman of the board and chief executive officer, Google Inc.

For more information about PCAST, go to *www.ostp.gov/cs/pcast*.

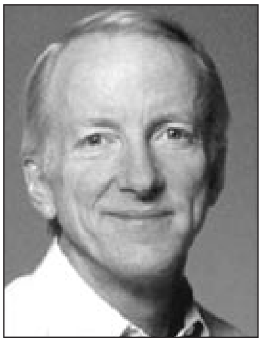
NAE Elects Treasurer and Councillors



C. Dan Mote Jr.

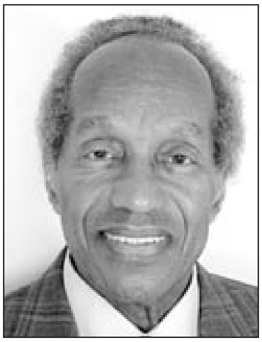


G. Wayne Clough

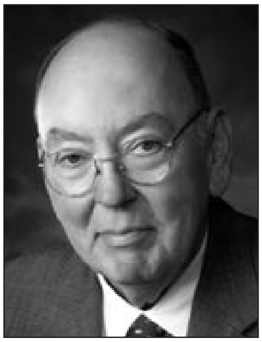


Robert F. Sproull

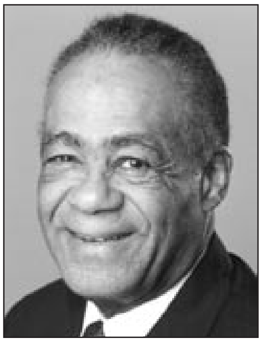
Corale L. Brierley



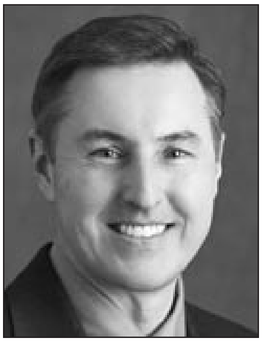
Arnold F. Stancell



William L. Friend



John Brooks Slaughter



William F. Banholzer

This spring, NAE elected a new treasurer, re-elected two incumbent councillors, and elected two new councillors. All terms begin July 1, 2009.

C. Dan Mote Jr., president and Glenn Martin Institute Professor of Engineering, University of Maryland, was elected to a four-year term as NAE treasurer. **G. Wayne Clough**, secretary of the Smithsonian Institution, and **Robert F. Sproull**, vice president and Sun Fellow, Sun Microsystems Inc., were re-elected to three-year terms as councillors. **Corale L. Brierley**, principal of Brierley Consultancy LLC, and **Arnold F. Stancell**, retired vice president of Mobil Oil and Turner Professor of Chemical Engineering Emeritus, Georgia Institute of Technology, were newly elected to three-year terms as councillors.

On June 30, 2009, **William L. Friend**, retired executive vice president of the Bechtel Group Inc., completed eight consecutive years of service as treasurer, the maximum allowed under the Academy's bylaws. **John Brooks Slaughter**, president and chief executive officer of the National Action Council for Minorities in Engineering, completed six continuous years of service as councillor, the maximum allowed under the Academy's bylaws. **William F. Banholzer**, executive vice president and chief technology officer of Dow Chemical Company, served one three-year term as councillor and chose not to stand for re-election. Dr. Friend, Dr. Banholzer, and Dr. Slaughter were recognized for their distinguished service and other contributions to NAE at a luncheon in May attended by NAE Council members and staff.

NAE Honors 2009 Prize Winners

The 2009 NAE prize winners were honored at an elegant dinner on February 17 at Washington, D.C.'s historic Union Station. This year's 2009 Charles Stark Draper Prize, Fritz J. and Dolores H. Russ Prize, and Bernard M. Gordon Prize recipients accepted their awards before an audience of more than 300 guests, with NAE President **Charles M. Vest** and NAE Council Chair **Irwin M. Jacobs** at the podium. Presenters at this year's ceremony were James D. Shields of the Charles Stark Draper Laboratory Inc., Roderick J. McDavis of Ohio University, and **Bernard M. Gordon**, founder of NeuroLogica Inc.

Charles Stark Draper Prize

Charles M. Vest; Robert H. Dennard, IBM Fellow and recipient of the 2009 Draper Prize; Irwin M. Jacobs; and Jim Shields, president and CEO, Charles Stark Draper Laboratory Inc.

Robert H. Dennard was awarded the 2009 Charles Stark Draper Prize for his invention and contributions to the development of the dynamic random access memory (DRAM), which is used universally in computers and other data processing and communication systems. The Draper Prize, one of the most prestigious honors in engineering, is a $500,000 award given annually to an individual(s) who has contributed to an achievement or body of work that has enhanced the well-being and freedom of humanity.

DRAM is a form of computer memory that puts bits of data into capacitors—energy-storage devices in a miniaturized electronic circuit—and periodically recharges the capacitors to ensure that the information is not lost. By using only a single metal-oxide-semiconductor (MOS) transistor—a device that conducts electricity, amplifying the charge as the electricity is passed along—Dennard was able to make his memory cell much smaller and simpler in design than its predecessor. The availability of cheap, high-density memory, made possible by the invention of the DRAM cell, enabled the tremendous growth in computing over the past 35 years.

Robert H. Dennard received his B.S. (1954) and M.S. (1956) in electrical engineering from Southern Methodist University in Dallas, Texas, and his Ph.D. (1958) in electrical engineering from Carnegie Institute of Technology in Pittsburgh, Pennsylvania—now Carnegie Mellon University. After completing his degrees, he joined IBM, where he continues his research today as an IBM Fellow. A member of NAE and a fellow of IEEE, Dr. Dennard has received many, many honors and awards, including the National Medal of Technology (1988), the Harvey Prize from the Technion (Israel, 1990), and the IEEE Edison Medal (2001). He was inducted into the National Inventors Hall of Fame in 1997.

The Draper Prize was established in 1988 and endowed by the Charles Stark Draper Laboratory Inc., Cambridge, Massachusetts, to honor the memory of "Doc" Draper, the "father of inertial navigation," and to increase public understanding of the contributions of engineering and technology to our quality of life.

Acceptance Remarks by Robert H. Dennard

Robert H. Dennard, fellow, IBM Thomas J. Watson Research Center, and recipient of the 2009 Charles Stark Draper Prize.

Thank you very much. I'm very grateful to the National Academy of Engineering for selecting me for this prestigious prize, and I appreciate the support of those who prepared and endorsed my nomination. It's a great honor for me, and it's a great honor for DRAM. The level of success that DRAM has achieved is due to a steady influx of new ideas and improved technology from thousands of people throughout the world. I'm happy to have contributed, along with my IBM associates, to some of those advancements.

So how did I get from a one-room schoolhouse in rural east Texas to this podium today? It had a lot to do with the values I learned from my family, which is very proud and self-reliant. My cousin Lucille, who is in the audience tonight, can attest to that. Throughout my education, a number of good, dedicated teachers gave me inspiration and guidance to get to the next level. After graduate school, when I got an offer to join IBM, which was just starting its research center, I didn't hesitate.

I feel very fortunate that I got involved in microelectronics in the mid-1960s when there were so many opportunities for new discoveries. I was blessed to be able to work with many outstanding colleagues, particularly **Dale Critchlow**, who was my close co-worker and manager in those early years. He asked me to find the best way to build memory chips using the new MOS technology we were exploring. My flash of inspiration for DRAM came one evening in late 1966 when I realized I could store binary data as charge levels on a tiny MOS capacitor. I was very excited that evening, but it took me a month to realize that I could use only a single transistor with that capacitor to form a very simple memory cell. Then I experienced the pleasure of knowing that I had discovered something significant.

Why is it called DRAM? The "D" stands for dynamic, which refers to the fact that the charge stored on the capacitor can decay in a fraction of a second due to leakage in the transistor. The charge has to be refreshed continuously by reading the data and writing new charge back into the capacitor. Some wags have lauded me for having the courage to propose a memory cell that is so forgetful.

In the early 1970s, a new project was started at IBM Research with the ambitious goal of drastically reducing memory costs by combining the simplicity of one-transistor DRAM cells with a five-fold reduction in all of the dimensions of the transistors and wiring of the integrated circuits. My small group, which was responsible for the MOS transistor design, came up with the scaling principles that could make it work, and our co-worker Hwa Yu was able to make our expectations come true in real devices and very small, experimental DRAM cells. When I gave a talk at a major conference in 1972, many appreciated the potential significant performance, cost, and power benefits of scaling, and it caught on quickly. I am proud to say that, with many process improvements, structural innovations, and plain hard work, the thousands of people who make up this industry have been able to scale down production integrated-circuit dimensions by 100 times since then, while building substantially bigger chips. This has had a great impact on all of microelectronics, and DRAMs with one-transistor cells, introduced by several manufacturers in 1974, have grown in capacity from 4 kilobits to 1 billion bits per chip.

In closing, I want to thank NAE once again for this great honor and to acknowledge the many people who have taught and inspired me. I thank IBM and my associates there for providing an environment where I can learn something new every day, have fun, and get paid to do the work I love.

Fritz J. and Dolores H. Russ Prize

Charles M. Vest; Irwin M. Jacobs; Elmer L. Gaden, Wills Johnson Professor Emeritus of Chemical Engineering at the University of Virginia and recipient of the 2009 Russ Prize; and Roderick McDavis, president of Ohio University.

Elmer L. Gaden was awarded the Fritz J. and Dolores H. Russ Prize, a $500,000 award given in recognition of a bioengineering achievement that has improved the human condition. Dr. Gaden was cited for pioneering the engineering and commercialization of biological systems that have enabled the large-scale manufacturing of antibiotics and other drugs.

Dr. Gaden's breakthroughs, which ensure that the proper amount of oxygen is available for the growth of antibiotics—known as "aerobic fermentation"—made possible the large-scale manufacture of inexpensive drugs. His achievements also initiated a multi-million dollar antibiotics industry and have immeasurably improved the human condition.

A World War II veteran, Dr. Gaden earned his Ph.D. in 1949 from Columbia University. After receiving his doctorate, he worked in research and development for Charles Pfizer & Co. in Brooklyn, New York (now Pfizer Inc., Groton, Connecticut), before returning to Columbia to teach. Dr. Gaden is a member of NAE and for several years was a member of the National Research Council Board on Science and Technology for International Development. During those years he led technical missions to Indonesia, Ethiopia, Portugal, Japan, and China.

Dr. Gaden is a fellow of the American Institute of Chemical Engineers and recipient of its Founders Award. He has also received the Egleston Medal for Distinguished Engineering Achievement from Columbia University and an honorary doctorate from Rensselaer Polytechnic Institute, Columbia's Great Teacher's Award, and the Mac Wade Award from the students of the School of Engineering and Applied Science at the University of Virginia.

The Russ Prize was established in 1999 and endowed by Ohio University with a gift from Fritz J. and Dolores H. Russ, benefactors of the Russ College of Engineering and Technology.

Acceptance Remarks by Elmer L. Gaden (read by Jennifer Gaden)

Jennifer Gaden reading the remarks of her husband, Elmer L. Gaden.

It is a great honor to receive the Russ Prize. I am both proud of and grateful for this recognition and want to thank those who have made it possible—the people at the National Academy of Engineering, those at Ohio University, and especially my friend and former student, Dr. Jerome Schultz, who initiated the nomination. This award recognizes work, some of which I did more than 50 years ago, and the prize tonight places a capstone on my career. Unlike T.S. Eliot's "hollow men," I am going out, professionally speaking, not with a whimper, but with a bang.

When one is 85 one does a lot of looking back—at least this one does. How is it that I came to accomplish the things for which I am being recognized tonight? I attribute my success to a combination of good genes, good luck, and good timing.

My parents were smart people, but their educations were limited. Nevertheless, they never failed to encourage the many interests I developed as a youngster. Early on I was very curious about chemistry, the life sciences, and history, and before I went to high school I was quite sure I wanted to be either an engineer or a doctor. I was lucky that I was able to attend Brooklyn Technical High School. In four years there, I learned a great deal about both science and technology, and my future as an engineer was set.

The timing of World War II was such that I turned 18 in my third year of college at Brooklyn Polytechnic Institute and immediately enlisted in the Navy. Through the V-12 program, the Navy sent me to Columbia University to complete my senior year in chemical engineering in six months. That introduction to Columbia University was another great break in my life. I saw for the first time what a great university was all about. During the war I served as a radar officer on an aircraft carrier in the Pacific, but as soon as I left the Navy, I headed straight back to the engineering school at Columbia.

My graduate work there gave me the opportunity and freedom to explore interactions between chemistry, biology, and engineering and to put this knowledge to use in developing solutions to problems that had real-world significance. A career followed that yielded great satisfaction from a number of accomplishments, some of which are being recognized here tonight, and from the lasting friendships that came from the people with whom I worked, particularly the graduate students. These friends have carried bioengineering forward into the twenty-first century, and many are leaders in the field today. Participating in their educations is, perhaps, my greatest contribution.

So, let me close by looking back again, this time to George M. Cohan, the great American entertainer. I will say, as he did many times at the end of a show, "Ladies and gentlemen—my mother thanks you, my father thanks you, my sister thanks you, and *I* thank you."

I thank you for this wonderful honor—the Russ Prize.

Bernard M. Gordon Prize

Charles M. Vest; Thomas H. Byers, professor, Stanford University, and Tina L. Seelig, executive director, Stanford Technology Ventures Program, Stanford University, recipients of the Gordon Prize; Bernard M. Gordon, and Irwin M. Jacobs.

The Bernard M. Gordon Prize for Innovation in Engineering and Technology Education was awarded to Thomas H. Byers and Tina L. Seelig of Stanford University for promoting engineering leadership, developing the Stanford Technology Ventures Program (STVP), and disseminating educational resources on technology entrepreneurship to engineering students and educators around the world. The Gordon Prize includes a stipend of $500,000, half of which is divided equally among the recipients and half of which is donated to the recipients' institution.

STVP is an education center that provides students across the university with entrepreneurial skills to facilitate the application of technological innovations to solving major world problems, with an emphasis on the environment, human health, and information technology. Based in the School of Engineering, STVP offers 25 different courses on entrepreneurship, innovation, and leadership and reaches nearly 2,000 students each academic year. Located in Silicon Valley, STVP draws upon nearby experts in the venture capital and technology fields for instruction and partnerships.

Thomas H. Byers is a professor at Stanford University and founder of the program, which includes the Mayfield Fellows Work/Study Program, the Entrepreneurship Corner website of videos and podcasts, and global Roundtable on Entrepreneurship Education (REE) conferences. Dr. Byers is co-author of *Technology Ventures: From Idea to Enterprise*, published by McGraw-Hill in 2005. He received the National Collegiate Inventors and Innovators Alliance (NCIIA) Olympus Innovation Award, American Society of Engineering Education Kauffman Award, and Gores Award, Stanford's highest honor for excellence in teaching. Byers is an active board member of several start-up companies, as well as the advisory councils of the World Economic Forum Global Agenda Council on Entrepreneurship, American Society for Engineering Education Entrepreneurship Division, and Harvard Business School California Research Center. He was executive vice president and general manager of Symantec during its formation.

Tina L. Seelig is the executive director of STVP, as well as the director of the Stanford Entrepreneurship Network and co-director of the Mayfield Fellows Program. Dr. Seelig earned her Ph.D. in neuroscience from Stanford University Medical School and has experience as an entrepreneur, management consultant, scientist, and author. She has written two popular science books on the chemistry of cooking and designed a series of educational games for which she won several national awards. Her newest book is *What I Wish I Knew When I Was Twenty* (Harper Collins, 2009). Dr. Seelig was awarded the NCIIA Olympus Innovation Award, NASDAQ Center for Entrepreneurial Excellence Award, USASBE National Model Program Award for Excellence in Entrepreneurial Education, and Leavey Award for Excellence in Private Enterprise Education. She also received the 2005 Stanford Tau Beta Pi Award for Excellence in Undergraduate Teaching.

The Gordon Prize, named in honor of **Bernard M. Gordon**, chairman of NeuroLogica Inc., and endowed by the Gordon Foundation, is given annually in recognition of significant advances in education, such as innovations in curriculum design, teaching methods, and technology-enabled learning that have led to the development of engineering leaders.

Acceptance Remarks by Thomas H. Byers

Thomas H. Byers

Tina and I are most humbled by this recognition. This prize is a huge honor for us and reflects all the work that goes on by the team at STVP, the School of Engineering, and Stanford University. Furthermore, I am in complete awe of the Draper and Russ Prize winners. To prove it, I have a DRAM in my pocket, and I took antibiotics for an infection just three weeks ago.

We want to thank many people for enabling the growth of our program. First, we thank Stanford's president, **John Hennessy**, who was dean of the School of Engineering when STVP was launched. His vision and support were critically important to its formation. We also want to thank our current dean, **Jim Plummer**, who is a constant source of encouragement and guidance. We thank our host department chair, **Elisabeth Paté-Cornell**, who has given us endless room to experiment and grow, and we thank our wonderful colleague and co-director at STVP, Professor Kathy Eisenhardt. I also wish to thank all the members of my family for their support and inspiration over the years.

Finally, we offer our heartfelt gratitude to the National Academy of Engineering, including the person responsible for this prize, **Bernard Gordon**, President **Chuck Vest**, all of our kind nominators, and the dedicated members of the selection committee.

This award is a great catalyst for us to find ways to bring together two robust and vital communities: people working on the future of engineering education and people who care about entrepreneurship education. In the coming year, Tina and I look forward to working on that convergence to find areas of common ground and exploit further opportunities for positive change. Now I would like to turn the podium over to my friend and co-recipient, Tina Seelig, who has been a true joy to work with over the past 10 years.

Acceptance Remarks by Tina Seelig

Tina Seelig

Exactly 24 years ago this week I was a newly minted Ph.D. in neuroscience. While in graduate school at Stanford Medical School, I spent time with a group of other science and engineering students lamenting that we had no idea how to translate our research findings into real-world products. We learned how to write research grants and publish papers, but we all wanted to know if there were broader applications for our discoveries and how to turn our ideas into viable products. As science and engineering students, there were no options available to us.

Flash forward 24 years. Today scientists and engineers in universities around the world have access to a growing number of ways to learn how to evaluate business opportunities, create strategic plans, lead in entrepreneurial environments, and build effective teams to bring their ideas to life. With their depth of domain expertise and their breadth of knowledge about leading and running successful organizations, they are ready to make major contributions to the world.

Tom Byers and I have spent the last decade together building the Stanford Technology Ventures

Program (STVP) with the goal of developing the next generation of technology entrepreneurs. Our mission is to educate a new breed of engineers and scientists who are prepared to tackle the big problems that face the world, especially problems related to human health and the environment. It is wonderful to know that we are succeeding. Every day we hear from students who are appreciative of the courses we teach on campus, as well as from students, professors, and entrepreneurs around the world who tap into our large collection of online resources. They tell us that they are as hungry as I was when I was a student for the tools to move their ideas out of the lab and into the world.

I want to thank Tom Byers for inviting me to join him a decade ago. He is a remarkable partner, a great role model, and a dear friend. I also want to thank my parents, who flew here from California to participate in this celebration, my husband Michael Tennefoss, as well as my Uncle Alan and Aunt Beverly Peterkofsky. My family was my first and best teacher, always asking me challenging questions and encouraging me to ask my own.

This prize is a huge honor that is a reflection of all of the work being done at STVP, the School of Engineering, and Stanford University.

Statement on President Obama's Executive Order and Presidential Memorandum, March 9, 2009

By Ralph J. Cicerone, President, National Academy of Sciences

Charles M. Vest, President, National Academy of Engineering

Harvey V. Fineberg, President, Institute of Medicine

On behalf of the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, we applaud the orders issued by President Obama today. By easing restrictions on federal support for embryonic stem cell research, the president's decision can hasten progress through stem cell research to treat disease and ease suffering. President Obama's executive order echoes the recommendations of a 2001 report[*] by the National Research Council and Institute of Medicine, which noted that public funding was the most efficient and responsible way to realize the medical promise of embryonic stem cell research. In his remarks at the signing ceremony, the president also echoed a recommendation in another of our reports[†] that reproductive cloning should not be used to create a human.

The National Research Council and Institute of Medicine have recommended guidelines for the ethical conduct of embryonic stem cell research that are currently used by many universities and other institutions to govern research in this field. We hope our guidelines will be helpful as the government proceeds to develop the guidelines for federal funding that the president called for today.

President Obama also issued a presidential memorandum directing the White House Office of Science and Technology Policy to establish standards to ensure that scientific advisers are appointed "based on their credentials and experience, not politics or ideology." This is welcome news because reliance on science that is free of political interference provides the foundation for public trust in government decision making.

The National Academy of Sciences, National Academy of Engineering, Institute of Medicine, and National Research Council stand ready now, as always, to bring scientific and technical expertise to bear on critical questions of national policy. Acting under a congressional charter, the National Academies are private, nonprofit institutions that provide science, technology, and health policy advice to the nation.

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[*] *Stem Cells and the Future of Regenerative Medicine* (National Academy Press, 2001).

[†] *Scientific and Medical Aspects of Human Reproductive Cloning* (National Academy Press, 2002).

2009 German-American Frontiers of Engineering Held in Potsdam

The twelfth German-American Frontiers of Engineering (GAFOE) Symposium was held April 22–25 at the Hotel Sanssouci in Potsdam, Germany. Located in the center of Potsdam opposite the Potsdam Brandenburg Gate and near the Park Sanssouci with its splendid palaces, the hotel provided a beautiful venue for the exchange of ideas that characterizes Frontiers symposia.

Modeled on the U.S. Frontiers of Engineering Symposium, this bilateral meeting brought together approximately 60 engineers ages 30 to 45 from German and U.S. companies, universities, and governments. Like its U.S. counterpart, the goal of GAFOE is to provide a forum where emerging engineering leaders can learn about cutting-edge developments in a variety of engineering fields, thereby facilitating interdisciplinary transfers of knowledge and methodology. GAFOE, like other bilateral Frontiers symposia, also helps build cooperative networks of younger engineers across national boundaries. NAE works with the Alexander von Humboldt Foundation to organize GAFOE symposia.

NAE member **Tresa Pollock**, L.H. and E.E. Van Vlack Professor in the Department of Materials Science and Engineering at the University of Michigan, and Kai Sundmacher, professor at the Max Planck Institute for Dynamics of Complex Technical Systems, co-chaired the organizing committee and the symposium. The four sessions at the meeting were: Materials for Extreme Environments; Biosystems Engineering—Engineering Biosystems; Complex Systems Design and Control; and Renewable Energy Sources.

Presentations, given by two Germans and two Americans on each of the four topics, covered mechanical materials and coatings that can survive the extreme environment of a gas-turbine engine, multiscale mechanobiology, complex systems in the chemical-process industry, microbial fuel cells, and many other research subjects. Spirited discussions among the participants filled the meeting space during formal sessions, as well as during breaks, receptions, and dinners, and poster sessions on the first afternoon gave all participants an opportunity to describe their research.

On Friday afternoon, the group was given a walking tour of Park Sanssouci, including the grounds of Sanssouci Palace, the summer residence and favorite domicile of Frederick the Great. A bus tour of Potsdam followed. Dinner that evening was held at the Restaurant Mövenpick zur Historischen Mühle Sanssouci.

Funding for the 2009 GAFOE Symposium was provided by the Alexander von Humboldt Foundation, National Science Foundation, U.S. Army Research Office, and The Grainger Foundation. Plans are under way for the 2010 GAFOE meeting, scheduled for April 23–25, 2010, at the Beckman Center in Irvine, California. NAE member **Dennis Assanis**, Jon R. and Beverly S. Holt Professor, Department of Mechanical Engineering at the University of Michigan, will serve as U.S. co-chair. Kai Sundmacher will continue to serve as the German co-chair.

For more information about GAFOE or other Frontiers programs, contact Janet Hunziker in the NAE Program Office at 202/334-1571 or by e-mail at *jhunziker@nae.edu*.

Engineering for the Body and for the Planet: NAE Regional Meeting at Columbia University

Prof. Nada Anid, dean of engineering, New York Institute of Technology; Van C. Mow, NAE member and Stanley Dicker Professor of Biomedical Engineering and chairman, Department of Biomedical Engineering, Columbia University; NAE President Charles M. Vest, and Nickolas Themelis, NAE member and Stanley-Thompson Professor Emeritus and director, Earth Engineering Center, Columbia University.

An NAE Regional Meeting was held on April 14 at Columbia University. The seminar was preceded by a luncheon for NAE members, which was also attended by President **Charles M. Vest**, Executive Officer **Lance Davis**, and Home Secretary **Thomas F. Budinger**. Dean Gerald Navratil of Columbia and President Vest welcomed the participants to the two-part seminar on bioinformatics (moderated by Professor **Mischa Schwartz**) and green energy (moderated by Professor **Alfred Aho**).

The first of three presentations in the session on bioinformatics, by Professor Dimitris Anastassiou (Columbia), was on using genome-wide data to discover the synergistic mechanisms that cause diseases. As biological datasets, such as gene-expression values and single-nucleotide polymorphisms, in the presence or absence of various diseases, become available, analyses of these data can help researchers and clinicians identify genetic biomarkers helpful for the diagnosis, prognosis, and prediction of responses to various drugs and can shed light on the mechanisms responsible for a given disease. However, because of the difficulty of identifying individual risk-conferring factors for several diseases, researchers also use novel graphical and computational tools based on the measure of a form of synergy to find *combinations* of jointly responsible factors.

In the next talk, Professor Mark Gerstein (Yale) discussed how network analysis is used to understand the protein function of genome scales. He described how networks can be identified in terms of topological statistics.

In the last presentation of the first session, Professor Ted Shortliffe (Arizona State) described the field of biomedical informatics, which deals with the storage, retrieval, and optimal use of biomedical data and information. This field has broad applications in all areas of biomedicine, ranging from molecular and cellular processes (*bioinformatics*), the management of structural or visual information about tissues and organs (*imaging informatics*), and patient-oriented tasks (*clinical informatics*) to population-based policy and analysis (*public health informatics*). He reviewed the evolution of the field—especially since the introduction of the Clinical Translational Science Awards (CTSA) Program at the National Institutes of Health and discussed how informatics could be used to personalize medicine.

The first speaker in the session on green energy was the famous geoscientist Professor Wally Broecker of the Lamont-Doherty Earth Observatory (Columbia), who graciously stepped in to replace Professor Klaus Lackner, who was unable to attend. Professor Broecker warned that, unless there is a revolution in energy infrastructures, the world faces a stark choice between economic growth and a healthy environment. We must stop the accumulation of CO_2 in the atmosphere, he said, while simultaneously improving energy services to a growing world population striving for a higher standard of living. We should promote dramatic new designs for a new generation of efficient, clean power plants that can capture CO_2 and store it safely and permanently. The remaining CO_2 emissions from distributed and mobile sources must be dealt with, either by replacing carbonaceous energy carriers with carbon-free energy carriers, such as hydrogen or electricity, or by compensating for CO_2 emissions by capturing an equivalent amount of carbon from the environment. The direct capture of CO_2 from the air would be the most efficient way to capture and store carbon and close the anthropogenic carbon cycle.

In the next talk, Professor Alissa Park (Columbia) summarized present techniques of carbon sequestration. Mineral carbonation, a relatively new technique, has the advantage of being the safest, most permanent method, because gaseous CO_2 is fixed into a solid matrix of magnesium-bearing minerals (e.g., serpentine) to form a thermodynamically stable solid product. The Lenfest Center at Columbia is developing a carbon capture and sequestration technology that might be integrated into gas and liquid fuel-production processes (e.g., biomass-to-liquid and waste-to-liquid).

In the last talk, **Prof. Nickolas Themelis** (Columbia) discussed existing technologies for reducing greenhouse gas (GHG) emissions and recovering energy from one billion tons of waste material that are presently deposited in landfills around the world. The only sustainable management of post-recycling wastes is either through controlled combustion with the recovery of energy and metals (also called waste-to-energy) or by capturing and using most of the biogas generated by landfills. Waste-to-energy processes help to conserve land and currently generate about 25 percent of the "renewable" electricity in the United States, excluding hydroelectric power. Columbia and North Carolina State Universities are conducting research in both areas at the Center for Sustainable Use of Resources (SUR; *www.SURcenter.org*).

The seminar was followed by an evening reception hosted by Professor **Van C. Mow** in the Low Rotunda at Columbia. Professors Mow (chair), Themelis (co-chair), Alfred V. Aho, **Steven M. Bellovin**, **Shree K. Nayar**, Mischa Schwartz, and **Joseph F. Traub** were members of the organizing committee.

Summit on NAE Grand Challenges

On March 2 and 3, Duke University, in collaboration with the Viterbi School of Engineering of the University of Southern California and Olin College, hosted a summit on the NAE Grand Challenges for Engineering (*www.engineeringchallenges.org*). About 1,000 people, including hundreds of students from around the state, braved a rare North Carolina snow storm to participate.

In the opening talk, NAE President **Charles Vest** encouraged the group to "change the conversation," change the way engineering is presented to the public and to young people by celebrating the power of great ideas and focusing on how engineers help bring those ideas to life. "We need to think about big challenges," Dr. Vest said, "because this world has plenty of them."

Six of the seven symposium sessions included a keynote address and a moderated panel discussion on one of the Grand Challenges: energy and the environment; health; entrepreneurship; security; understanding the brain; and Big Ideas. The seventh was a presentation of the findings of a national survey conducted by Hart Research Associates and commissioned by the Duke Pratt School of Engineering in anticipation of the summit.

Tom Katsouleas, dean of the Pratt School presented the findings. "Americans understand that innovation is critical to their future but also recognize that our country's continued leadership isn't assured just because we invented everything from the airplane to the personal computer," he said. "The survey shows that when Americans focus on how central engineers are to solving our biggest problems, they come to view the discipline as essential and want to attract more talented young people to it."

The young people who attended were enthusiastic participants in the summit. In a description of the gathering in *Business Week*, the writer noted, "It is one thing for students to choose engineering over finance by necessity as the finance sector implodes. It's entirely another to have students so excited about engineering and science that they are willing to sit in an overflow room to watch video monitors of onstage proceedings."

The three organizing schools announced the Grand Challenges Scholars Program, a combined curricular/extra-curricular program for preparing students to address the Grand Challenges. The program will include research experience; an interdisciplinary curriculum called Engineering+, which will include projects and classes on entrepreneurship and the global dimension of complex problems; and service learning. Participating schools will select 25 to 30 of their top students for the program. Rick Miller, the president of Olin College, explained the purpose of the program, "We need to change the way we educate engineers—we need to produce young minds that are comfortable integrating and seeing themselves as leaders." He called on other schools to follow the lead of the Scholars Program and create similar programs on their campuses.

In addition to the sessions described above, awards were presented to the winners of a video/essay contest sponsored by Duke University as part of its educational outreach in conjunction with the summit. More information about the summit, including the winning entries in the video/essay contest, can be found at *http://summit-grandchallenges.pratt.duke.edu*.

NAE Annual Meeting, October 4 and 5, 2009

The 2009 NAE Annual Meeting will be held October 4 and 5 at the Marriott Newport Beach Hotel and Spa and the Beckman Center of the National Academies in Irvine, California. Members of the NAE Class of 2009 will meet on Saturday, October 3, for an orientation. That evening the new members will attend a black-tie dinner in their honor hosted by the NAE Council.

The induction ceremony for the Class of 2009 will be held at noon on Sunday, October 4. An awards program will follow, featuring talks by the winners of the 2009 Founders Award, Arthur M. Bueche Award, and Bernard M. Gordon Prize, and the Armstrong Endowment for Young Engineers-Gilbreth Lectures.

The topic for the forum on the morning of October 5 will be "Rebuilding a Real Economy—Unleashing Engineering Innovation." Activities will continue with section meetings in the afternoon and a dinner dance at the Marriott Newport Beach Hotel and Spa.

Registration materials and information will be sent to all members in June.

Calendar of Meetings and Events

June 17	NAE/NAEF Finance and Budget Committee Conference Call
June 18	NAE/NAEF Audit Committee Meeting
June 25–26	Workshop on Engineering Faculty as Academic Change Agents Chicago, Illinois
July 9	NRC Governing Board Executive Committee Meeting
July 13–17	Council of Academies of Engineering and Technological Sciences (CAETS) Calgary, Canada
July 20–25	U.S.-China Cooperation on Electricity from Renewables Joint Committee Meeting Qinghai Province, China
July 29–30	NAE Council Meeting Woods Hole, Massachusetts
July 31–August 1	NRC Governing Board Meeting Woods Hole, Massachusetts
August 31–September 1	Committee on Women in Science Meeting Engineering, and Medicine Workshop on Entrepreneurship Irvine, California
September 9	NRC Governing Board Executive Committee Meeting
September 10–12	U.S. Frontiers of Engineering Symposium Irvine, California

All meetings are held in the Academies Building, Washington, D.C., unless otherwise noted.

In Memoriam

LEO ROY BEARD, 91, Professor Emeritus, University of Texas at Austin, died on March 21, 2009. Mr. Beard was elected to NAE in 1975 "for leadership in statistical applications and system analyses in hydrologic design and operation."

L.G. "GARY" BYRD, 85, retired, consulting engineer, died on March 20, 2009. Mr. Byrd was elected to NAE in 1987 "for pioneering contributions to highway maintenance management systems and research."

JOHN L. GIDLEY, 84, president, John L. Gidley and Associates Inc., died March 30, 2009. Dr. Gidley was elected to NAE in 1994 "for development of stimulation materials and techniques to increase oil and gas production."

FRANK E. PICKERING, 77, retired vice president and chief engineer, GE Aircraft Engines, died on March 3, 2009. Mr. Pickering was elected to NAE in 1990 "for distinguished contributions and outstanding leadership in the design and development of aircraft gas turbine engines that set new world performance standards."

ROBERT O. REID, 87, Professor Emeritus of Oceanography, Texas A&M University, died on January 23, 2009. Professor Reid was elected to NAE in 1985 "for pioneering contributions to hydrodynamical theory/applications, wave force analysis, storm tide prediction, tsunami flooding estimation, and for superlative teaching."

WILLARD F. SEARLE JR., 85, U.S. Navy, retired, died on March 31, 2009. Captain Searle was elected to NAE in 1982 "for worldwide leadership in the development and application of ocean engineering technologies to marine rescue and salvage."

RICHARD F. TUCKER, 82, retired vice chairman, Mobil Corporation, died on January 31, 2009. Mr. Tucker was elected to NAE in 1987 "for fostering an atmosphere for integrating research and engineering with innovation, and for pioneering macro-engineering technologies in the petroleum and chemical areas."

OLGIERD C. ZIENKIEWICZ, 87, Research Professor, Emeritus, Institute for Numerical Methods in Engineering, University of Wales, died on January 9, 2009. Dr. Zienkiewicz was elected an NAE Foreign Associate in 1981 "for outstanding contributions to development of finite element method theory and dissemination of knowledge concerning its application to engineering practice."

Publications of Interest

The following reports have been published recently by the National Academy of Engineering or the National Research Council. Unless otherwise noted, all publications are for sale (prepaid) from the National Academies Press (NAP), 500 Fifth Street, N.W., Lockbox 285, Washington, DC 20055. For more information or to place an order, contact NAP online at <*http://www.nap.edu*> or by phone at (888) 624-8373. (*Note: Prices quoted are subject to change without notice. Online orders receive a 20 percent discount. Please add $4.50 for shipping and handling for the first book and $0.95 for each additional book. Add applicable sales tax or GST if you live in CA, DC, FL, MD, MO, TX, or Canada.*)

Systems Engineering to Improve Traumatic Brain Injury Care in the Military Health System: Workshop Summary. This NAE report makes a strong case for taking advantage of the best of two disciplines—health care and operational systems engineering (OSE). OSE is a combination of science and mathematics used to describe, analyze, plan, design, and integrate systems with complex interactions. Thus OSE tools might be used to improve the efficiency and quality of health care delivery, as well as health care outcomes. The U.S. Department of Defense (DOD) and Department of Veterans Affairs have expressed a strong interest in pursuing this approach to improve the quality of care for military personnel, veterans, and their families. In pursuit of that goal, DOD decided to sponsor a series of workshops to explore the potential of applying OSE principles and tools to military health care, beginning with the diagnosis and care of soldiers with traumatic brain injury (TBI), a prevalent injury suffered by soldiers in Iraq and Afghanistan. The report includes suggested scenarios in which OSE might be used to improve TBI care.

NAE members on the study committee were **Norman R. Augustine** (co-chair), retired chairman and CEO, Lockheed Martin Corporation; **Seth Bonder**, The Bonder Group; **Thomas F. Budinger**, professor, Department of Bioengineering, University of California, Berkeley, and head, Department of Functional Imaging, E.O. Lawrence Berkeley National Laboratory; **Paul M. Horn**, NYU Distinguished Scientist in Residence, Courant Institute, New York University; and **William B. Rouse**, executive director and professor, Tennenbaum Institute, Georgia Institute of Technology. Paper, $43.50.

Future of the Nuclear Security Environment in 2015: Proceedings. The National Academies and the Russian Academy of Sciences (RAS), building on a foundation of years of cooperative efforts, conducted a joint project to determine and describe U.S. and Russian views on what the international nuclear security environment will look like in 2015, including the challenges that may arise and options for the United States and Russia to work together to address those challenges. The discussions took place during a two-day public workshop at the International Atomic Energy Agency in November 2007. A key aspect of the U.S.-Russian partnership would be cooperation based on their joint activities over the last 10 years on non-proliferation issues. The subjects that have been analyzed in these joint discussions have included: a culture of safety and security, the protection of nuclear materials, best practices in control and accounting (MPC&A), sustainability, nuclear forensics, public-private partnerships, and the expansion of the peaceful use of nuclear energy.

NAE member **Cherry A. Murray**, principal associate director for science and technology, Lawrence Livermore National Laboratory, was a member of the study committee. Paper, $65.75.

Assessment of Corrosion Education. The dangers of degradation of the materials in engineered products that drive our economy, keep our citizens healthy, and protect us from terrorism and other threats have been well documented over the years. The study committee for this report argues that the engineering workforce must have a comprehensive understanding of the physical and chemical bases of corrosion, as well as of the engineering issues surrounding corrosion and corrosion abatement. The committee offers short- and long-term recommendations for industry and government agencies, educational institutions, and communities for improving education and increasing public awareness of the effects of corrosion and ensuring that incoming workers are fully aware of potential problems and possible solutions.

NAE members on the study committee were **Wesley L. Harris** (chair), Charles Stark Draper Professor of Aeronautics and Astronautics, Massachusetts Institute of Technology; **George E. Dieter**, Glenn L. Martin Institute Professor of Engineering, University of Maryland; **Frank E. Karasz**, Silvio O. Conte Distinguished Professor, Department of Polymer Science and Engineering, University of Massachusetts; and **Ronald M. Latanision**, corporate vice president and director, Mechanics and Materials, Exponent Inc. Paper, $38.00.

Restructuring Federal Climate Research to Meet the Challenges of Climate Change. Policy decisions are already being made to limit the effects and adapt to the impacts of climate change, as necessary, but often these decisions are being made without a proper consideration of science. The study committee for this report proposes six priorities for restructuring the U.S. climate change research program to develop a more robust knowledge base and support informed responses: (1) reorganize the program around integrated scientific-societal issues; (2) establish a U.S. climate observing system; (3) support a new generation of coupled models of Earth systems; (4) support more research on adaptation, mitigation, and vulnerability; (5) initiate a national assessment of the risks and costs of the impacts of climate change and potential responses; and (6) coordinate federal efforts to provide decision makers with climate information, tools, and forecasts on an ongoing basis.

NAE member **Robert E. Dickinson**, professor, Jackson School of Geosciences, University of Texas, Austin, was a member of the study committee. Paper, $55.75.

Computational Technology for Effective Health Care: Immediate Steps and Strategic Directions. Medical errors, ineffective treatment, and other persistent problems continue to plague the health care industry. Many of these problems reflect the lack of information and technology (IT) capabilities and, most important, the lack of cognitive IT support. This report advocates that the portfolio of investments in health care IT be rebalanced to put more emphasis on providing cognitive support for health care providers, patients, and family caregivers; observing proven principles for success in designing and implementing IT; and accelerating research related to health care in the computer and social sciences and in health/biomedical informatics. Health care professionals, patient safety advocates, and IT specialists and engineers will find this report a useful tool.

NAE members on the study committee were **Alfred Z. Spector**, vice president of research and special initiatives, Google Inc., and **Andries van Dam**, Thomas J. Watson Jr., University Professor of Technology and Education and professor of computer science, Brown University. Paper, $35.00.

Assessing the Impacts of Changes in the Information Technology R&D Ecosystem: Retaining Leadership in an Increasingly Global Environment. In the mid-1990s, the U.S. information technology (IT) research and development (R&D) ecosystem was the envy of the world. However, leadership is not a birthright, and U.S. leadership in this area is now under pressure. In recent years, the rapid globalization of markets, labor pools, and capital flows have encouraged many strong national competitors. During that same period, U.S. policies have not sufficiently protected the U.S. IT R&D ecosystem, or have generated side effects that have undermined its effectiveness. The study committee for this report calls for a new commitment to providing the resources necessary to promote and support IT innovation, to removing roadblocks to innovation, and to becoming a lead innovator and user of IT. This report includes discussions of these issues and recommendations for reinvigorating the U.S. IT R&D ecosystem.

NAE members on the study committee were **Randy H. Katz** (co-chair), United Microelectronics Corporation Distinguished Professor, University of California, Berkeley; **Edward D. Lazowska**, Bill & Melinda Gates Chair in Computer Science and Engineering, University of Washington; and **Raj Reddy**, Mozah Bint Nasser University Professor of Computer Science and Robotics, Carnegie Mellon University. Paper, $45.25.

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