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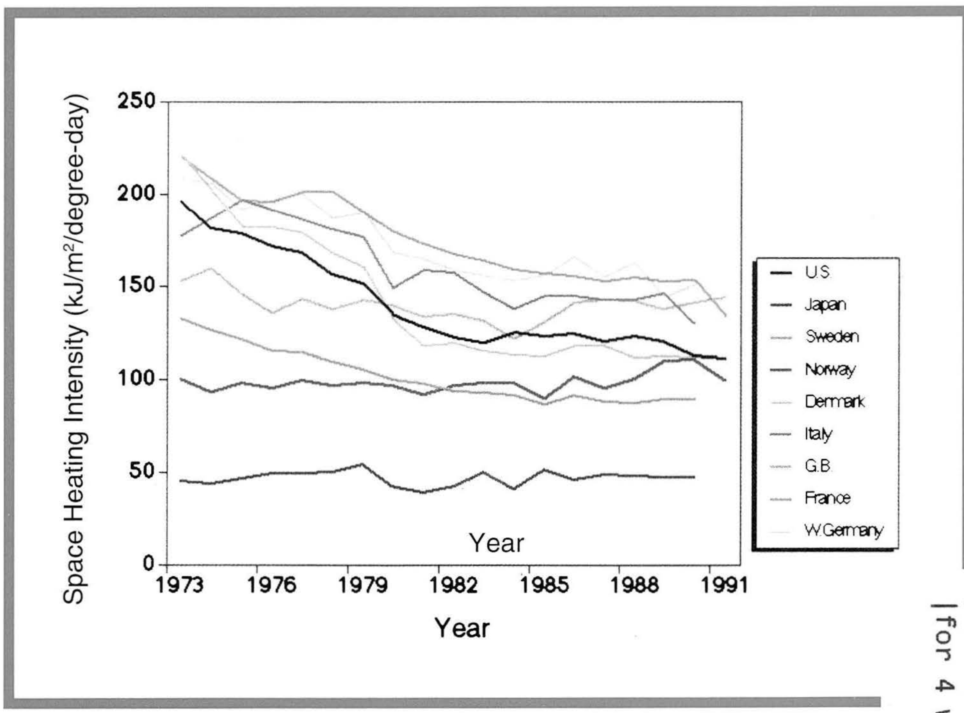
Energy Analysis Program

1993 Annual Report



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Shown on cover: Graph produced by Energy Analysis Program researchers indicates recent progress in residential energy efficiency.

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Energy Analysis Program
1993 Annual Report

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Report No. LBL-35240

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Introduction

With the new federal Administration in place, we have observed increasing attention in the areas of research and analysis that have been central to our interests. Energy efficiency is once again a very high priority in the national agenda. This increased emphasis on energy efficiency was already apparent prior to the national elections in the contents of the National Energy Policy Act (EPACT), passed by Congress in 1992. The *Climate Change Action Plan*, released by the White House in October 1993, strengthens the federal government's leadership role in the design and implementation of energy-efficiency programs. Budget submissions show energy efficiency and renewable energy programs among the relatively small number of discretionary programs at the federal level that are expected to receive large percentage increases.

Were it not for severe budgetary concerns, all of this might suggest a return to the days of the late 1980s when energy efficiency was a very high federal priority and research projects were strong and growing. Under the present budgetary austerity, new activities are likely to evolve more cautiously. Nonetheless, we believe that we are again entering a time in which new opportunities for expansion in fruitful areas will be possible. We also expect that the results of the work of the Energy Analysis Program will continue to have influence on U.S. energy policy deliberations, or have even greater influence.

Some major achievements of the individual research activities include:

- research demonstrating the ability of white surfaces and trees to reduce air-conditioning loads in homes and small commercial buildings;
- assessment of the effects of modifying temperature in the Los Angeles basin on the formation of photochemical smog;
- a detailed analysis of the costs and performance of energy-efficiency measures for eight household appliances that will serve as the basis for federal appliance efficiency standards, with 1500 pages of supporting material;
- expansion of the integrated resource planning (IRP) activities from electric utilities to the gas industry, resulting in a technical primer on gas IRP;
- analyses of policies to increase energy efficiency in residential buildings as an input into the national *Climate Change Action Plan;*
- a cross-country analysis of automobile fuel economy, gasoline prices, and driving behavior in industrialized countries;
- continuing in-depth analyses of the structure of energy demand and energy efficiency in a number of industrialized countries, republics of the former USSR, and Poland;
- analyses of costs of measures in selected developing countries to reduce the growth of carbon emissions from the energy sector; assessment of measures to reduce emissions or increase sequestration from forests;
- development of energy-efficiency pilot projects for Mexico;
- in-depth energy-efficiency studies of China, and creation of the Beijing Energy Conservation Center (BECon); and

(cont.)

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Introduction *cont.*

- development of data and tools that will permit much-improved forecasts of commercial building energy use and analysis of policies to promote energy efficiency in that sector.

This is a highly selective list of some of our key achievements in the past year. The reader is strongly encouraged to read this full report to gain a fuller understanding of our work. Some of our expectations for the coming year are:

- expansion of the research on heat islands, with considerable emphasis on expanded measurements and the development of more advanced analytic methods;
- a significant expansion of the analysis for appliance standards to encompass fourteen residential products; initiation of analysis of selected commercial products;
- increases in our training and educational activities on demand-side management and IRP for developing countries;
- assessment of cogeneration opportunities in China, in addition to continued work on end-use energy efficiency;
- participation as lead and contributing authors in energy and forestry sections of the next Intergovernmental Panel on Climate Change international report; and
- active involvement in the debate among economists, energy efficiency analysts, and policy researchers about the existence and magnitude of the so-called energy-efficiency gap (i.e., energy-efficiency measures that are judged to be cost-effective but are not often chosen by consumers) and its policy implications.

Two areas of considerable importance to the Program in the coming year are our participation in the U.S. country studies activities and the development of the database of energy-efficiency programs (DEEP). The country studies involves a major effort by the U.S. government to provide technical and analytical support to developing countries to increase their understanding of greenhouse gas emissions and approaches to reduce their growth. We have been chosen to serve as the technical lead for the mitigation portion of the country studies. The DEEP project, intended to provide an initial basis for assessing the performance of utility demand-side management programs, is continuing to develop the database and has recently completed its first report on commercial lighting programs.

One area of major disappointment has been the inability of the Department of Energy to obtain the planned funding for the Assisting Deployment of Energy Practices and Technologies (ADEPT) program, an activity originally proposed by us and colleagues at Oak Ridge National Laboratory.

An area of major success during the past year has been the performance of our new Washington, D.C. Project Office. This office has been instrumental in gaining us involvement in many important and interesting energy activities in Washington. We believe that this office, combined with the rekindled interest in energy efficiency at the federal level and the many capabilities within our Program, places us in an excellent position to undertake new and exciting activities over the coming years.

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Building Energy Analysis

Building Energy Compilations

A.K. Meier

Staff in the Building Energy Analysis Group participate in numerous projects to collect and compile field measurements of building energy use. Together these compilations are called Building Energy-use Compilation and Analysis (BECA).

The actual energy use of buildings and equipment, and the savings from energy efficiency measures, are essential elements of forecasting and policy development. Such information will confirm (or refute) the efficacy of new, efficient designs, savings from retrofits, and cost effectiveness. Over the past eight years, the Group has compiled data on the monitored performance of new commercial office buildings, thermal storage systems, multifamily retrofits, single-family retrofits, refrigerators, and office equipment. Because the Group does not actually monitor buildings, it depends on data contributions from other building researchers.

A recent study examined the monitored savings from space heating retrofits to fuel-heated multifamily homes. This compilation showed that furnace equipment improvements and system modifications had by far the shortest payback times and often the largest savings. On the other hand, window retrofits saved little energy (Figure 1).

Another study compared the actual electricity use of refrigerators to the energy use predicted by laboratory tests (and shown on the yellow "Energy Guide" labels). The compilation showed that, although there are large individual variations in energy use among refrigerators, the label predicted with reasonably accuracy the average energy of a large number of units (Figure 2).

New, low-energy homes are the current focus of our compilation activity. The concept of low-energy homes was traditionally equated with low space heating. Advances in energy-efficient design have been so successful that space heating is now often only the third largest end use in superinsulated homes, so it is essential to include the other uses, such as water heating and appliances, in future definitions of low energy. In addition, an increasing fraction of the U.S. building stock is located in regions where air-conditioning energy use is larger than that for space heating. For this reason, low-cooling-energy homes are also being examined.

Future compilations will include monitored savings from commercial building HVAC retrofits, residential water-heating retrofits, and documentation of exemplary low-energy commercial buildings.

Reference

Meier AK. Field performance of residential refrigerators. *ASHRAE Journal* 1993; 35 (8): 37.

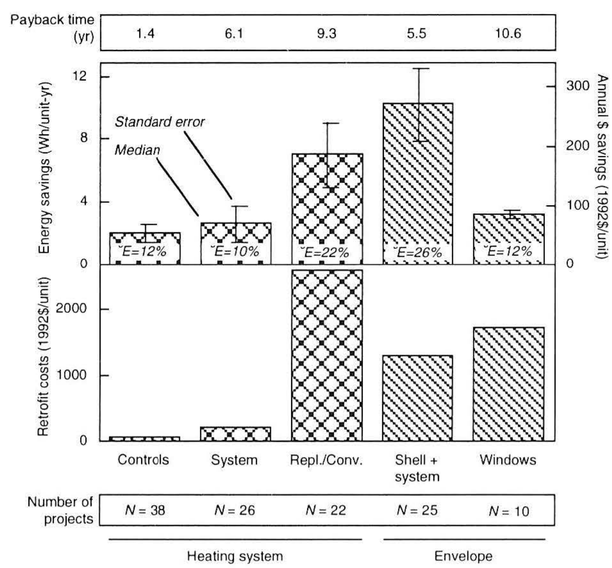

Figure 1. *Median energy savings, costs, and payback times for fuel-heated multifamily buildings for various retrofit strategies. "System" retrofits are groups of measures that affect the heating or hot water systems. "Repl./Conv." includes boiler replacements or conversions from steam to hot water distribution. "Shell + system" includes heating/hot water system measures as well as insulation or window retrofits.*

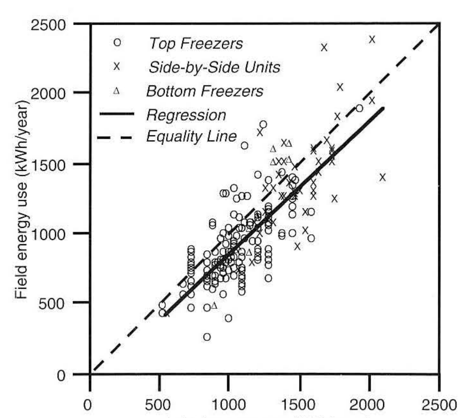

Figure 2. *A comparison of labeled and field annual electricity use. Each symbol represents one refrigerator. The dashed line indicates equal consumption in label and field, while the solid line represents a regression fit.*

Six Years of Post-Construction Data for New Commercial Buildings in the Energy Edge Program

M.A. Piette, B. Nordman, O. de Buen, R.C. Diamond, K. Heinemeier, K. Janda

Twenty-eight commercial buildings have been built in the Pacific Northwest to assess the cost effectiveness of several hundred energy efficiency measures. Sponsored by the Bonneville Power Administration, the Energy Edge buildings were designed to use 30% less energy than a baseline building built to meet the regional energy code, called the Model Conservation Standards (MCS). The 28 buildings are typical of new commercial construction in the region: office buildings, schools, fast-food restaurants, strip retail establishments, medical clinics, a supermarket, and a convenience store. Floor areas range from 2,000 ft^2 to more than 1,000,000 ft^2 and most s paces have all-electric fixtures.

LBL has been assessing the actual energy use in the buildings and comparing it with that of other new buildings in the region as well as with results from computer simulation models. We have as much as six years of measured energy use for the buildings and have analyzed "tuned" simulation results (calibrated with monitored data) for 15 of the buildings.

The Energy Edge buildings as a group are using more energy than predicted, but they are, for the most part, low-energy users when compared to other new construction in the region. Based on the first three years of utility bills, the average energy use for 14 offices is about 13 kWh/ft^2-year, slightly higher than predicted, but well below regional benchmark data (Figure). Energy consumption for all 28 buildings, based on the third year of utility bills, was increasing in 60% of the buildings. By the sixth year of operation, energy use is no longer climbing among the seven buildings for which we have six years of energy-use data. In fact, we found the first average decrease in energy use (by 3%) between the fifth and sixth year.

Among the 37 measures with both predicted and tuned energy-savings data, the measures are saving only 58% as much energy as predicted. Many measures were not installed or were dropped from the analysis because of ambiguities about the baseline conditions. Some of the decrease in energy savings is attributed to poor commissioning and operations and maintenance practices.

Among all 65 measures with cost data, 40% met the target cost-of-conserved energy (CCE) of 5.6 cents/kWh (1991 dollars). Among the various measures installed at the buildings, the three refrigeration measures were the most cost-effective, with all three measures meeting the CCE criteria. Shell measures (n=33) were the next most cost-effective (median of 6.3 cents/kWh), followed by lighting (n=12, median of 8.9 cents/kWh), and heating, ventilation, and air-conditioning measures (n=14, median of 14.6 cents/kWh).

The Energy Edge evaluation has provided a wealth of information on the performance of energy efficiency measures in new commercial buildings. Bonneville is using project results to provide guidance for commercial program design, to upgrade commercial codes, and to revise conservation supply curves. The data are also helpful in identifying problems with individual measures, improving future applications, and better defining commissioning, control, and operation and maintenance procedures to optimize energy savings.

Reference

Piette MA, Nordman B, de Buen O, Diamond RC, Cody B. Predicted vs. monitored performance of energy-efficiency measures in new commercial buildings from Energy Edge. In: N. Collins (Ed.) *Proceedings of the 1993 International Energy Program Evaluation Conference. August 25-27, 1993, Chicago, IL.* Oakland CA: Becilacqua-Knight, Inc., 1993, p. 682.

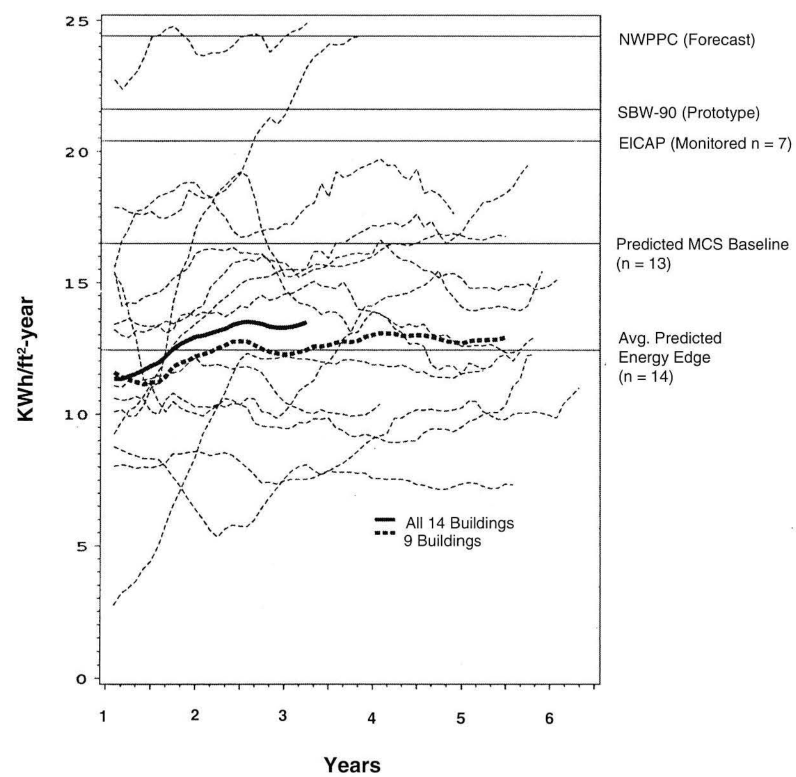

Figure. *Rolling average annual electricity use for 14 Energy Edge office buildings with regional comparison data. ELCAP data are from 7 post-1980 all-electric office buildings. NWPPC are 1989 regional forecasts for new construction. SBW are prototypes for 1989 current practice. The predicted MCS baseline is the average code baseline from early designs.*

Integrated Estimation of End-Use Load Shapes and Energy-Use Intensities for Commercial Buildings

H. Akbari, J. Eto, S. Konopacki, A. Afzal

The objective of this project is to apply a new end-use load shape estimation technique to develop annual energy-use intensities (EUIs) and hourly end-use load shapes (LSs) in commercial buildings serviced by the Pacific Gas and Electric Company (PG&E). The project's results will update input for the commercial sector energy- and peak demand-forecasting models used by PG&E and the California Energy Commission. EUIs are estimated for 11 building types, up to 10 end uses, 3 fuel types, 2 building vintages, and up to 5 climate regions. End-use electric LSs are of special interest for typical weekdays, weekend days, and peak days, by month and by season.

The 11 building types studied were small office, large office, retail store, restaurant, food store, warehouse, school, college, health (hospitals and nursing homes), lodging (hotels and motels), and miscellaneous buildings. The 10 end uses included space heating, space cooling, ventilation, indoor lighting, outdoor lighting, refrigeration, cooking, office equipment, and miscellaneous end uses.

The project was designed in two phases. Phase I included three building types (small office, large office, and retail store) and was completed in May 1992. Phase II encompasses the remaining eight building types and commenced in September 1992.

The core data for the project included: 1) PG&E onsite survey data of 855 buildings, including billing data and weights; 2) short-interval (30-minute), whole-building load data from more than 1000 accounts for two years (1985-1986); 3) PG&E's commercial sector end-use mail surveys (~6000 for 1988); and 4) hourly weather data for five climate regions.

The integrated methodology consists of two major parts. The first is the reconciliation of initial end-use LS estimates with measured whole-building load data to produce intermediate EUIs and LSs. The model used for this reconciliation is the End-use Disaggregation Algorithm (EDA). EDA is a deterministic hourly algorithm that relies on the observed characteristics of the *measured* hourly whole-building electricity use and disaggregates the total energy use into major end-use components (Table). The end-use EUIs developed through the EDA procedure represent a snapshot of 1986 electricity use by building type and end use for two of PG&E's service regions.

In the second part of the methodology, we adjust the 1986 EUIs for direct application to forecasting models based on factors such as climatic impacts on space-conditioning EUIs, fuel saturation effects, building and equipment vintages, and price impacts.

Reference

Akbari H, Eto J, Konopacki S, Afzal A. *Integrated Estimation of Commercial Sector End-Use Load Shapes and Energy-Use Intensities in PG&E Service Area.* Lawrence Berkeley Laboratory Report LBL-34263, 1993.

Table. *1986 commercial buildings end-use EUIs in PG&E's inland service area (kWh/ft^2-year).*

	Non-HVAC End Uses						HVAC				
Building Type	**Indoor Lighting**	**Outdoor Lighting**	**Misc. Equip.**	**Office Equip.**	**Refrig.**	**Cooking**	**Water Heating**	**Heating**	**Fans**	**Cooling**	**Total**
Small Office	4.62	1.54	1.39	1.11	0.17	0.03	0.12	0.05	0.57	3.13	13.09
Large Office	10.48	0.44	2.14	1.73	0.09	0.15	0.05	0.00	4.03	5.71	26.36
Retail Store	7.05	0.82	0.75	0.24	0.47	0.03	0.04	0.12	0.80	2.24	12.56
Restaurant	7.63	1.97	5.87	0.07	6.80	3.69	0.26	0.00	5.73	5.17	37.19
Food Store	13.97	1.29	6.40	0.06	15.15	0.50	0.11	0.00	4.43	4.61	46.52
Warehouse	1.81	0.52	2.31	0.22	6.97	0.00	0.01	0.00	0.92	0.74	13.50
School	3.06	0.28	0.17	0.15	0.25	0.07	0.16	0.00	0.62	0.05	4.81
College	3.59	0.11	0.23	0.22	0.04	0.04	0.05	0.00	1.43	1.29	7.00
Health	10.98	0.36	7.23	0.90	0.24	0.16	0.01	0.00	2.49	4.74	27.11
Lodging	2.78	0.41	0.98	0.05	0.53	0.04	0.00	0.43	1.27	1.33	7.82
Misc.	1.84	0.39	2.45	0.16	0.43	0.00	0.00	0.00	1.13	1.10	7.50

Monitoring Building Performance Using Energy Management and Control Systems

K.E. Heinemeier, H. Akbari

Although costs can be high, effective monitoring of energy consumption and building operations is an important part of conservation savings analysis. Energy Management and Control Systems (EMCSs) contain much of the same equipment that is usually installed for monitoring and can often be used for this application as well. Since EMCSs are installed in an increasing number of commercial buildings, the addition of conventional energy-monitoring equipment can be redundant.

EMCSs are not, however, designed with end-use monitoring in mind. The characteristics of an EMCS are determined by building needs rather than by monitoring needs, so EMCS-based monitoring can encounter several complicating factors. Differences between the EMCS models, the installed options at sites with the same model, or the degree of system utilization at a site can mean the difference between a system that can be immediately used for monitoring and one that cannot be used at all. These differences are often difficult to assess.

In earlier years, we evaluated the use of EMCSs for monitoring in several different cases and developed guidelines for EMCS monitoring based on these evaluations. The guidelines discussed how to determine if the necessary elements were present and what to do if they were not. In the past year, we tested these guidelines in a few cases and evaluated their usefulness in the assessment process. During the evaluation, we found that in new-generation EMCSs with complex network architectures and multi-tasking capabilities, there are new methods for accessing the systems and transferring data. The method with the most promise is based on windowed software (illustrated in the Figure), where data are automatically written to an EMCS computer disk in a format designed to be read by other software, and remote access is made through a window running in parallel with the EMCS software on the same EMCS computer. This change should enhance the usefulness of EMCSs for monitoring in future years.

Another issue identified was that less tangible factors can override the technical aspects of EMCS monitoring covered by the guidelines. One emphasis of the work, then, focused on investigating the non-technical issues that are quite important in using equipment that is owned by the building management and that was designed for control rather than monitoring functions. The people involved in energy management and EMCS operations at several sites were interviewed to explore some of these non-technical aspects. To use an in-place EMCS for monitoring requires assistance from on-site personnel for assessing capabilities, reconfiguring aspects of the system, and in helping in various ways while carrying out the ongoing monitoring. In all monitoring projects, but especially with EMCS monitoring, it is important to identify who, within the organization, has the information, resources, and incentive to be able to provide assistance.

In order to investigate further some of these technical and non-technical issues, we began an in-depth case study of EMCS monitoring. In this project, we are studying an institutional laboratory building that was the subject of a pilot study of shared savings. An outside contractor installed retrofits and a fraction of the savings realized by the owner will be paid to the contractor, who is responsible for monitoring the building and estimating the savings. The method for determining savings from the retrofits was clearly specified in the contract and will include using the EMCS for monitoring. To verify these savings estimates, the owners have installed their own submetering. In this project, the savings estimates resulting from the EMCS-based monitoring and the more conventional submetering will be compared. In addition, more detailed engineering estimates of savings will be made, taking into account operational and consumption data collected by the EMCS, and the project will compare both the resulting savings estimates and the different *processes* for collecting and analyzing data.

Reference

Heinemeier K, Akbari H. *Energy Management and Control Systems and Their Use for Performance Monitoring in the LoanSTAR Program.* Lawrence Berkeley Laboratory Report No. LBL-33114, 1993.

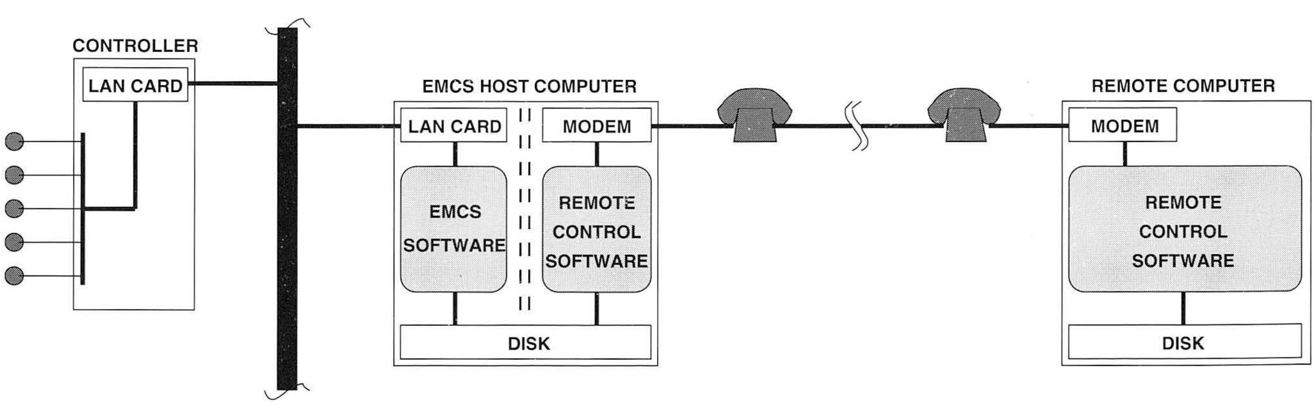

Figure. *One possible configuration for carrying out remote building monitoring using an EMCS. In this example, EMCS software and remote control software (used to establish communications) run in parallel on the EMCS host. The remote monitoring computer can retrieve data from the EMCS host's disk while the host continues to carry out EMCS functions.*

Low-Energy Cooling Techniques

Y.J. Huang

Low-energy or alternative cooling techniques refer to those that can provide comfort during the cooling season without using air conditioning. These techniques include improving the building design to minimize heat gain; using ventilative and evaporatively cooled air, or the ground, as cooling sources; increasing a building's thermal mass to provide thermal stability or permit night cooling; and using ventilation, cooled ceilings, and improved controls to deliver cooling to the space.

Such cooling techniques are appropriate in areas of the U.S. where the demand for air conditioning has grown steadily. Air conditioning not only consumes a great deal of electricity, but also contributes to utility peak electricity demands. These characteristics are particularly evident in new residential construction in California, where air conditioning is often regarded as essential, even though summer conditions are relatively mild and dry. This growing use of compressor-based cooling is energy-intensive and extremely disadvantageous to the utility companies that must meet intermittent peaks on hot summer afternoons that coincide with system peaks.

Since low-energy cooling techniques are characterized by limited cooling capacity and interact strongly with the building design and operations, LBL has been investigating the appropriateness of using low-energy or alternative cooling techniques in residential and commercial buildings in California and elsewhere. The "Alternatives to Compressive Cooling in California Transition Climates" project is supported by the California Institute for Energy Efficiency (CIEE) and focuses on the design and construction of residential houses in inland transition climates that will not require air conditioning. The "Low-Energy Cooling" project is an International Energy Agency (IEA) activity supported by DOE to study the use of low-energy cooling techniques in commercial buildings in collaboration with European and Canadian researchers.

Alternatives to Compressive Cooling in California Transition Climates

This three-year project started in the fall of 1992 with a team of seven researchers from LBL and four California universities. In the first year, the project focused on research in the areas of modeling natural ventilation, evaporative cooling, improved building controls, monitoring the effects of shading and thermal mass (see Figure), laboratory study of the effect of air flow on human comfort, and sociological study of the institutional and sociological barriers to alternative cooling strategies. The project activities for the second year include continued research into design, operations, and health issues, design assistance to local builders, and a design workshop to develop house plans using alternative cooling techniques.

Low-Energy Cooling

In contrast to the CIEE project, the focus of this IEA project is on the application of low-energy cooling techniques to commercial buildings. The following technologies have been identified as the most promising: evaporative cooling, cooled ceiling (with and without displacement ventilation), night and slab cooling, and desiccants. The goals of the project are to develop detailed analytical tools, to develop simple design tools, and to conduct demonstration projects of these cooling technologies. LBL will lead the research on evaporative cooling and will contribute to that of cooled-ceiling technology.

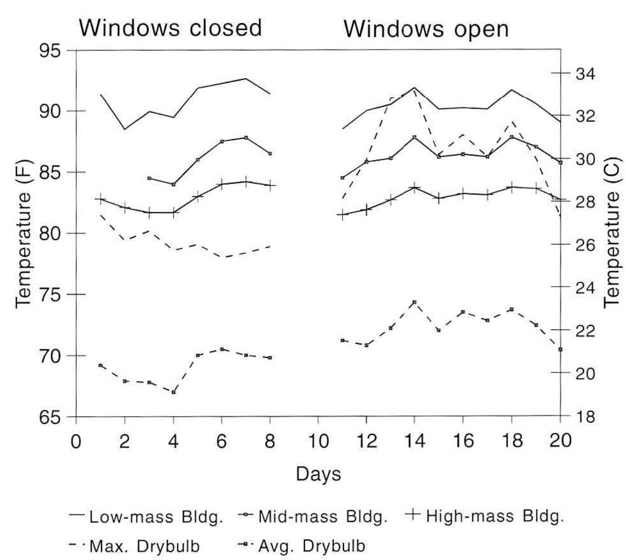

Figure. *Effect of window ventilation on indoor temperatures in three test buildings with varying amounts of thermal mass.*

Energy Conservation in Public Housing

Y.J. Huang

For the past three years, LBL has been providing technical assistance to the U.S. Department of Housing and Urban Development (HUD) through the DOE/HUD Initiative. Two current projects are 1) to evaluate the energy performance of a prototypical straw-bale and adobe house built by the Housing Services Department of the Navajo Nation in Arizona, and 2) to monitor and evaluate the energy savings of cooling energy retrofits being installed in two large public housing projects in Sacramento, CA.

Navajo Straw-Bale/Adobe House

Straw-bale construction has been used in rural areas of the U.S. since the frontier days. Contrary to common perception, this type of housing has proved to be durable, with many built more than 80 years ago still standing today. With recent concerns about energy efficiency and the use of renewable materials, straw-bale construction has received serious attention as an ecological and energy-conserving alternative to conventional wood-frame construction. The construction material is cheap and readily available, and no special skills or tools are needed to make straw-bale houses. The R-value of a straw-bale wall is estimated to be around R-60.

In December 1992, LBL staff attended a Housing Symposium in Gallup, NM, to address the severe housing shortage of the Navajo Nation. After comparing various construction systems, the Symposium selected a straw-bale/adobe housing design on the bases of its ease of construction, use of local materials, adaptability to native architectural traditions, and energy efficiency. A prototypical house was constructed on the reservation in the fall of 1993 (Figure).

LBL scientists are now evaluating the energy and comfort performance of this prototypical house through a combination of field measurements, monitoring, and computer simulations. Since the walls represent only one of its components, determining the overall energy performance of the building and identifying design and construction defects, or areas for improvement, is equally important. This study is particularly needed for this prototypical house because of its mixed construction.

Sacramento Public Housing Project

The Sacramento Housing and Redevelopment Agency (SHRA), the Sacramento Municipal Utility District (SMUD), and LBL are all involved in this collaborative project. Through its lead-abatement program, SHRA is implementing a major retrofit of two large 1960-vintage public housing projects, including the use of energy-conserving measures such as ground-source heat pumps, evaporative coolers, and light-colored roofs. SMUD is providing rebates for these cooling measures and is installing monitoring equipment to record their performance. LBL is providing technical guidance for the monitoring effort and will analyze the measured data to determine the cost effectiveness of the energy-conserving measures. LBL will also investigate design issues such as the impact of building orientation on indoor comfort or cooling energy use.

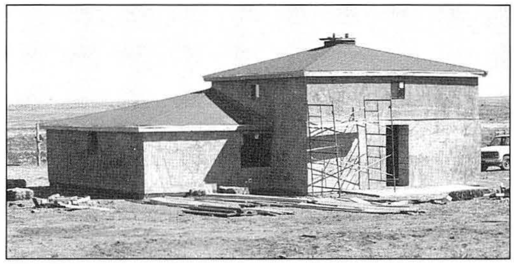

Figure. *Navajo straw-bale/adobe house.*

DEEP: The Database on Energy Efficiency Programs

E. Vine, J. Eto, C. Payne, L. Shown, R. Sonnenblick

A national database on energy efficiency programs (DEEP) is being established at LBL. DEEP will provide program descriptions and key summary data on program costs, energy and demand savings, participation rates, cost effectiveness, and evaluation methodologies. The goal of DEEP is to lower the costs to utilities of promoting customer energy efficiency by reducing or eliminating the need for utilities to "re-invent the wheel" with each new demand-side management (DSM) program plan or design. The information in the database will be national in scope, up to date, and accessible to all interested parties.

In the past year, DEEP researchers and other LBL staff members completed the following work related to the project: 1) collected over 250 DSM program evaluations from utilities around the country; 2) conducted a market research study with over 150 DSM professionals to examine their awareness and use of, and the extent to which they value, information services; 3) began work on an in-depth analysis of 21 utility-sponsored commercial lighting programs for preparation of a commercial lighting report; 4) prepared a report on glossaries of terms used in DSM evaluation and monitoring for the Association of Demand-Side Management Professionals (ADSMP); 5) conducted a mail survey of ADSMP members on current and future program evaluations within their organizations; 6) completed several LBL reports and conference papers on DEEP and evaluation issues; 7) helped develop an implementing agreement for the International Energy Agency (IEA) member countries, which was recently signed by IEA member countries; and 8) conducted a scoping study to determine the interest of developing countries in an international energy efficiency program database.

Plans for the DEEP project include periodic publication of "Lessons Learned" reports, which will present research results related to particular types of DSM programs. DEEP's first "Lessons Learned" report addresses commercial lighting programs and will be available by early 1994. In the report, we analyze 21 utility-sponsored commercial lighting programs, focusing on post-program estimates of energy savings, total program costs (including customer costs), and estimates of measure lifetimes. We analyze these data in a consistent fashion to allow direct comparability among programs. Through our research, we have found the mean total resource cost of the programs to be 4 cents/kWh with a standard deviation of 2 cents/kWh, indicating that commercial lighting programs represent a cost-effective energy resource. In addition, our research indicates that, on average: 1) large programs (measured by total savings) are less expensive than small programs; 2) programs targeting large savings per participant tend to have lower societal costs than those programs with lower savings per participant; and 3) free riders (participants who would have installed the same measures without participating in the program) have a very small impact on the total resource costs of these programs, ranging from less than 0.1 cents/kWh to about 0.4 cents/kWh.

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Progress in Residential Energy Retrofits

A.K. Meier, B. Pon

Tens of millions of major residential energy-saving retrofits have been implemented in the United States in the last decade. However, little is known about what retrofits were done and the actual energy savings that have resulted. Data on retrofit activities are extremely sparse because retrofits are undertaken by diverse parties—individuals, utilities, and government agencies. At the same time, the energy-conservation industry is fragmented with few large suppliers or national associations. The lack of detailed information on residential retrofits hampers the creation of policies to encourage cost-effective measures.

This project created a snapshot of residential retrofit activities. The project focused on estimating the saturation and rate of implementation of major residential conservation measures such as insulation, low-emissivity windows, and efficient furnaces.

No single source of data offers a comprehensive assessment of residential retrofit activities. With the exception of the data gathered through DOE's Residential Energy Consumption Survey (RECS), retrofit data are scattered and inconsistent. Many sources provide insights into a specific aspect of the activities but are limited to a small area, a small group of projects, or a single technology. To obtain a comprehensive overview, data must be pieced together from numerous sources.

Many utilities, for example, collect data on retrofit activities in their service areas, such as the amount of insulation sold or homes audited or certified. Most utilities periodically conduct customer surveys (commonly called residential appliance saturation surveys or RASSes) to monitor appliance purchases, conservation activities, and customer attitudes. Examples of retrofit measures surveyed in a typical RASS are floor insulation, wall insulation, attic or ceiling insulation, storm doors and windows, caulking and weatherstripping, and water-flow restrictors. We have collected more than one hundred RASSes from utilities. Our collection of surveys offers a more complete picture than the RECS because the cumulative sample size of our RASSes encompasses more than 800,000 homes, compared to 6000 for RECS.

Other sources of retrofit activity data include individual manufacturers of conservation supplies, installation companies, and industry organizations involved in the residential energy-conservation industry (insulation, fenestration, heating and air-conditioning equipment, appliances, and so on). Information from these sources provides estimates of specific retrofit progress.

By linking the various sources of data into a comprehensive study, this project has obtained a mosaic of retrofit measures already implemented and has established the rate at which implementation is occurring. When assembled, these data can be represented geographically. For example, ceiling fans offer an important alternative to air conditioning by raising the critical temperature at which air conditioning is needed and by precooling homes prior to use of an air conditioner. One would expect that the saturation of ceiling fans would be highest in the warmest states. The RASSes indicate that ceiling fans are generally more common in the south than in the north, but the highest saturations occur in the Mississippi and Ohio River Valleys (Figure). This suggests that people have different cooling strategies and that the effectiveness of efficiency improvements to air conditioners may differ greatly, depending on the region.

Future surveys will need to shift their focus to the quality of the retrofits rather than to merely their presence or absence. For example, most ceiling insulation activity is now in the form of upgrading insulation levels ("re-insulation") and double-glazed windows are rapidly increasing in quality and number in U.S. homes.

Reference

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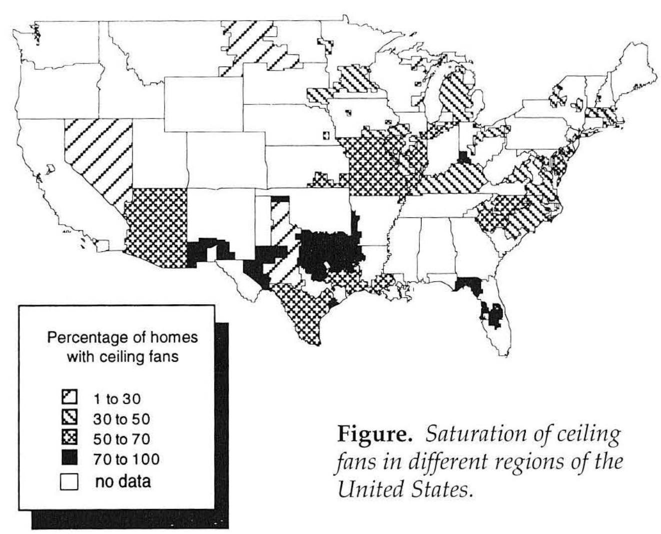

Figure. *Saturation of ceiling fans in different regions of the United States.*

Temperature Dependence of Refrigerator Energy Use

A.K. Meier

Refrigerators represent the largest end use of electricity in U.S. homes. Understanding the factors that affect energy use will enable us to forecast electricity demand more accurately and improve laboratory test procedures. Considerable data have been collected on the energy use of refrigerators, but little data were collected about the conditions that occurred during the measurement period, such as ambient temperature, door openings, and internal temperature settings. Laboratory measurements suggested that ambient temperature was the most important determinant of refrigerator energy use, but other occupant-driven factors could also be responsible.

In cooperation with the Rochester Gas & Electric Corporation and the State of New York, we analyzed electricity use and kitchen temperatures for 22 refrigerators in homes in Rochester, New York.

Energy consumption and temperatures were collected every 30 minutes for one year.

Individual refrigerators demonstrated a clear linear relation between kitchen temperature and energy use. The slope of the regression line (Fig. 1) is a function of the refrigerator's efficiency and location in the kitchen. However, once these factors have been accounted for, essentially all variation in daily energy use appears to be caused by fluctuations in kitchen temperature. This suggests that door openings, ice making, and food loading are less critical in determining energy use.

The results were aggregated for all 22 refrigerators, again showing a strong correlation between kitchen temperature and energy use. The robust nature of this relation is shown (Fig. 2).

Reference

Meier AK, Megowan A, Litt B, Pon B. *The New York State Residential Refrigerator Electrical Energy Monitoring Project.* Lawrence Berkeley Laboratory Report No. LBL-33708, 1993.

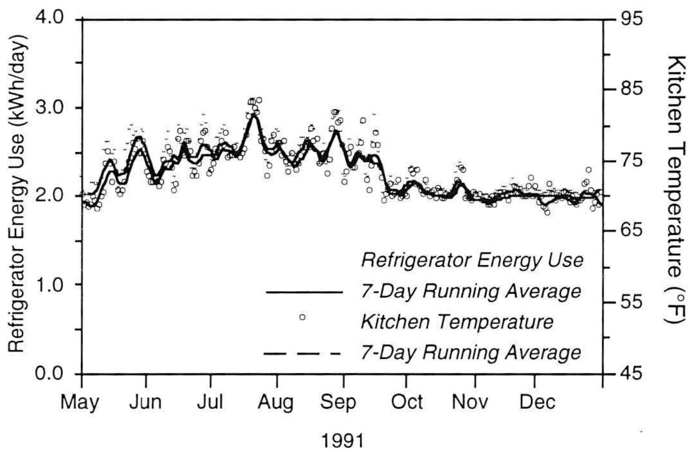

Figure 1. *Relation between ambient kitchen temperature and energy use for a single refrigerator.*

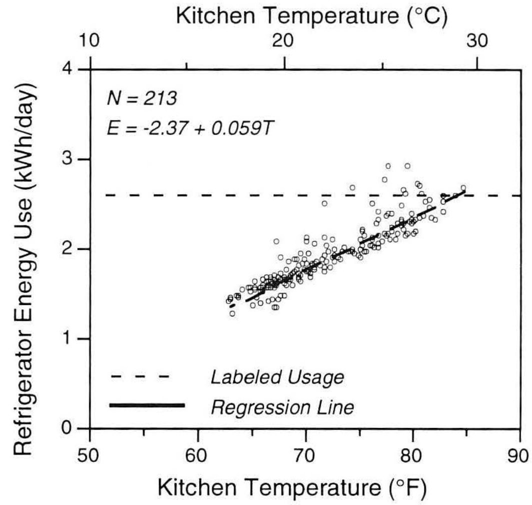

Figure 2. *Relation between ambient kitchen temperature and energy use for 22 refrigerators.*

The Conservation Verification Protocols

A.K. Meier

The need to verify energy savings has become increasingly important as utilities incorporate energy efficiency programs into their long-term energy plans. We have developed savings-verification protocols for the U.S. Environmental Protection Agency as part of the Clean Air Act requirements. When utilities verify energy savings with the Conservation Verification Protocols (CVP), they are entitled to sulfur emissions allowances. These allowances can be used when their power plants burn fuels containing sulfur or they can be sold to other utilities.

The CVP are strongly oriented toward verification based on direct monitoring but also try to give the utilities as much flexibility as possible (Figure). The CVP's goal is to verify the savings of the utilities' demand-side management programs, not critique the verification programs. Nevertheless, the CVP hope to encourage better verification by giving utilities more savings.

Two features of the CVP are unique. First, the CVP do not specify the precise verification procedure; instead, they outline a general approach and a necessary confidence level for the verified savings. This allows the utility to select the evaluation plan and monitoring technologies that best suit their conservation program at the lowest cost. Second, the CVP offer a list of "stipulated savings." This list allows utilities to claim savings through engineering calculations, extrapolations of short-term measurements, or simple per-unit savings. The goal is to simplify verification where savings are known to be reliable or easily predicted and encourage energy monitoring for less certain measure savings. In addition, the stipulated savings are deliberately set low enough to encourage monitoring when utilities believe that larger savings may have actually occurred.

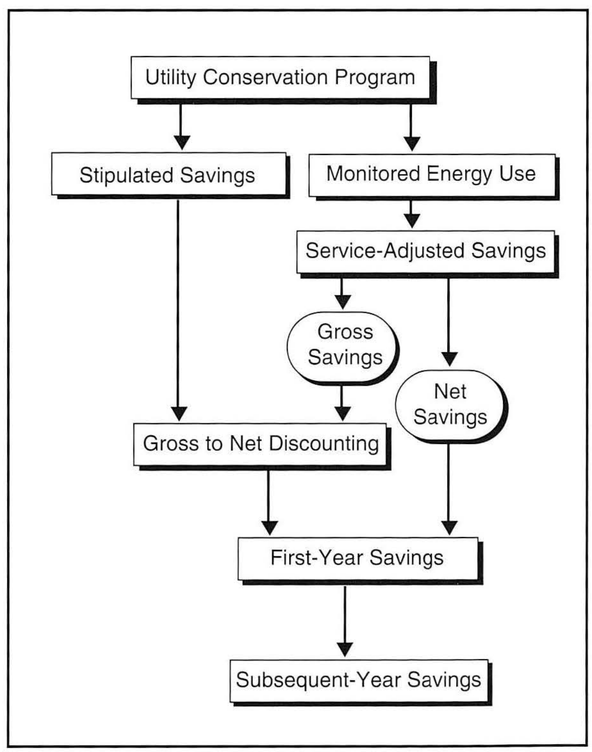

Figure. *Overview of verification options for the Conservation Verification Protocols.*

The CVP are independent of the specific Clean Air Act regulatory details. Thus, they can be easily transferred to future legislation requiring verification of energy savings. The CVP are being considered for use in verifying CO_2 savings related to the Energy Policy Act.

Reference

U.S. Environmental Protection Agency, *Conservation Verification Protocols: A Guidance Document for Electric Utilities Affected by the Acid Rain Program of the Clean Air Amendments of 1990.* Washington, DC: U.S. Environmental Protection Agency, March 1993.

Peak Power and Cooling Energy Savings of Shade Trees and White Surfaces

H. Akbari, S. Bretz, J. Hanford, D. Kurn, B. Fishman, H. Taha

We have monitored the impact of shade trees and white roofs on peak power and cooling energy use on five buildings in Sacramento, CA. This two-year project started in May 1991. From mid-August through October 1991 data were obtained for base energy use and limited post-retrofit results and also to validate and refine the data-collection system. We summarized the FY 1991-1992 measurement efforts and results in the first-year final report. The estimates of savings provided in the 1991 final report were based on data collected during the end of the cooling season and they were considered preliminary. Monitoring in the second year, 1992, focused on obtaining data for an entire cooling season. The 1992 project consisted of 1) monitoring the air-conditioning energy savings of shade trees and albedo changes in two temporary school buildings and three houses in Sacramento, 2) performing DOE-2 simulations of the monitored buildings, and 3) comparing simulation results with the monitored data.

In 1992, the monitoring began in May and continued through October. For most sites, we collected data on air-conditioning electricity use, indoor and outdoor dry-bulb temperatures and humidity, roof and ceiling surface temperatures, inside and outside wall temperatures, insolation, and wind speed and direction. Analysis of the data indicated that shade trees in two houses resulted in seasonal cooling energy savings of 30%, corresponding to an average daily savings of 3.6 and 4.8 kWh/day in each of the houses. Peak demand savings on a hot day were 0.6 and 0.8 kW, about 23% and 22%, respectively (Figure). The cooling energy savings at one of the albedo sites (a house) was 2.2 kWh/day when the daily average temperature was below 25 °C, or almost 70% of the cooling energy use under these conditions. The average peak demand savings was 0.56 kW. (Base-use data were not collected when average outdoor temperature exceeded 25 °C.) The average cooling energy and peak demand savings in the second albedo site (school buildings) were about 4.4 kWh/day and 0.57 kW, respectively.

Simulations with the DOE-2.1E program generally agreed with the measured data. However, the simulations may underpredict the effects of shade trees. We used the measured data to calibrate the simulation models. We also developed six DOE-2 prototypical building models and simulated the impact of a variety of shade tree and albedo options on their cooling energy use. The simulation results were adjusted using the calibration factors developed from the comparison of the measured and simulated data for the monitored buildings. Simulations indicated that shading the walls and part of the roof of an "average" house with as many as eight trees and increasing the albedo of its roof from 0.2 to 0.7 results in savings of more than 65% of cooling energy use. Simulated peak demand savings were 30 to 60%, depending on the prototypical building type and its orientation.

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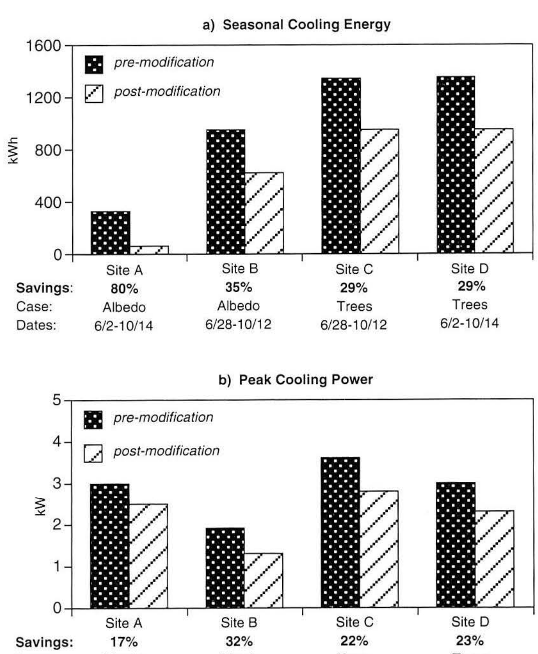

Figure. *Peak power and seasonal cooling energy use for the monitored sites before and after modification of albedo or shading. Seasonal cooling energy usage was estimated based on the regression of weekday cooling energy use and daily average temperatures.*

The Impact of High-Albedo Surfaces on Air Temperature

B. Fishman, H. Akbari, H. Taha, A. Rosenfeld

White Sands is a unique geological site that lies within the White Sands Missile Range in New Mexico. This site provides an opportunity to study the impacts of albedo variation on near-surface air temperature. White Sands is a large gypsum flat, which consists of approximately 225 km^2 of gypsum sand dunes and sparsely vegetated inter-dune areas. The dunes have an albedo of 0.55-0.60 and the inter-dune areas may have an albedo as low as 0.39. The transition areas, however, have an albedo of ~0.29-0.53. The entire gypsum flat is approximately 1225 km^2 and is situated in a valley.

Summer weather data from ten weather stations at White Sands were analyzed. The data, provided to us by the White Sands Meteorological Team, included hourly dry-bulb, dew point, and soil temperatures, wind speed and direction, solar radiation, and precipitation. The stations we analyzed have approximately the same elevation (±30m). All data were screened for quality and rainy days were excluded in order to minimize the need to consider moisture effects.

Of ten stations, one station outside the dunes (approximately 50 km upwind with an albedo of 0.23) was defined as the control (C-Station) and was used as the basis for comparison with the others. Ratscat and Northrup are the only stations within the high-albedo area. Located to the northwest of the highest albedo area, they have predominantly gypsum surfaces and an albedo estimated at 0.50. The Figure shows daytime average air temperature plotted against daytime average soil temperatures, measured 1 cm below the surface, on non-rainy days in August 1992. The dashed line represents the equality line for soil temperature and air temperature. Both daytime average air and soil temperatures at Ratscat were lower than those at C-Station.

Analysis of weather data at White Sands demonstrates the existence of a large-scale cooling effect. This effect may be as much as 2 °C during afternoon hours. This temperature depression, however, is a function of atmospheric stability and solar radiation, as well as albedo. In the coming fiscal year, we will continue this research in order to understand better how albedo impacts the surface air temperatures.

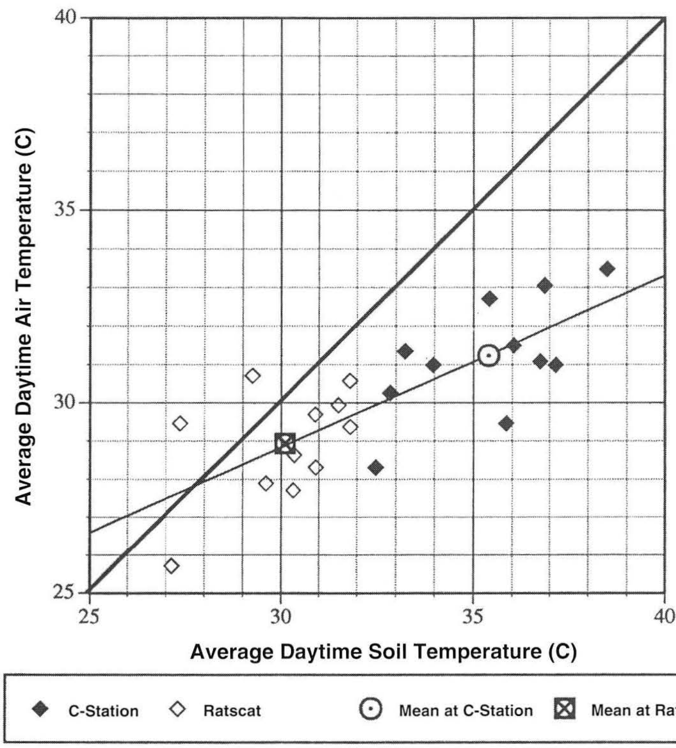

Figure. *Average daytime air temperature and soil temperature for Ratscat (inside the White Sands dunes, albedo ~0.50) and C-Station (outside the dunes, albedo ~0.24) for non-rainy days in August 1992. The mean air and soil temperatures at Ratscat are about 1.5 °C and 5.5 °C, respectively, cooler than at C-Station.*

Increasing Solar Reflectivity of Urban Surfaces: Implementation Issues

S. Bretz, H. Akbari, A. Rosenfeld, H. Taha

With specific examples for Sacramento, CA, this work focuses on implementation issues for using solar-reflective surfaces to cool urban heat islands. Advantages of solar-reflective surfaces to reduce energy use are 1) their cost effectiveness if albedo is increased during routine maintenance; 2) energy savings that coincide with peak demand for power; 3) the positive effects on environmental quality; and 4) the long service life of white materials. When reflective materials are chosen for mitigating heat islands, such factors as albedo, emissivity, durability, cost, pollution, and appearance must be taken in consideration.

We estimate the potential for increasing urban albedo in Sacramento to be approximately an additional 18%, taking into account that asphalt shingles and modified bitumen cover the largest area of residential roofs and that built-up roofing and modified bitumen cover the largest area of commercial buildings. For all of these roof types, albedo can be increased at the time of re-roofing without any additional cost. When a roof is repaired, a solar-reflective roof coating can be applied to increase albedo significantly and extend the life of the roof. Although a coating can be cost-effective if applied to a new roof following installation or to an older roof following repair, it is not cost-effective if the coating is applied only to save energy.

Solar-reflective street pavement can

also be cost-effective if the albedo change is included in the routine resurfacing schedule. Options for producing light-colored pavement include: 1) asphalt concrete, if white aggregate is locally available, 2) concrete overlays, 3) newly developed white binders and aggregate, and 4) hot-rolled asphalt with white chippings. We find that there are methods of changing the albedo of all major urban surfaces (streets, parking lots, flat and sloped roofs) at the time of resurfacing or re-roofing for less than the avoided cost of electricity.

Programs to promote solar-reflective surfaces should be designed taking into account the interests of consumers, building and roofing contractors, utilities, and local or state governments. Legislation might include a labeling program for paints and roof materials and albedo specifications for new pavement surfaces. Utilities could promote solar-reflective surfaces through advertisement, educational programs, and sharing the cost of road resurfacing.

Reference

Bretz S, Akbari H, Rosenfeld A, Taha H. *Implementation of Solar-Reflective Surfaces: Materials and Utility Programs.* Lawrence Berkeley Laboratory Report No. LBL-32467, 1992.

Durability of High-Albedo Roof Materials and Implications for Cooling-Energy Savings

S. Bretz, H. Akbari, H. Taha

Using high-albedo materials on exterior building surfaces is an effective strategy for reducing air-conditioning electricity use. Our studies showed that in Sacramento, CA, a high-albedo coating reduced cooling-energy usage by 45% for a temporary school building (R-19 roof) and by 70% for a home (R-11 roof). By lowering the absorption of solar energy on the exterior, high-albedo materials reduce heat transfer to the interior of the building. These materials also reduce convective heat transfer to the surrounding air, thereby reducing the contribution to urban heat islands.

A good-quality roof coating will last for ten or more years when applied to a roof that is in sound structural condition. To maximize cooling-energy savings, high-albedo materials should have 1) high solar reflectivity, 2) high infrared emissivity, and 3) high albedo and high emissivity over a number of years. A literature survey provided no quantitative information on the durability of high-albedo coatings.

As part of a joint project with the Sacramento Municipal Utility District, LBL made field measurements to determine the effects of dust and soot residues and weathering on high-albedo coatings. Several high-albedo coatings were identified, and for each, several roofs that had been surfaced with the coating were selected. The albedo of each roof was measured with a high-precision radiometer. Some of the roofs were then washed with soap and water in an attempt to return the albedo to the original value and measurements were repeated. When washing was not possible, the measurements of aged roofs were compared to the albedo of the same coating on a similar surface before dust accumulation.

The figure shows albedo measurements vs. age of the coating. Each symbol is identified by a number, which indicates the coating and a substrate type (smooth, medium, or rough). In general, a rough surface lowers the albedo of a coating because less reflected light is able to escape. In one case, the same coating had an albedo of 0.15 lower on a rough surface than on a smooth surface. There was also significant variability among coatings: on a rough substrate, the difference between #3 and #1 was 0.19.

On average, the reduction in albedo after one year of dust and soot accumulation was 0.15, or 18% of an average initial reflectivity of 0.75. The range was from 0.04, or 6%, to 0.23, or 29%. The reduction in albedo for most of the roofs that were exposed to two, four, and six years of dust and soot residues was in the same range, indicating that the largest decrease in albedo occurs in the first year, and later incremental reductions in albedo in the second to sixth year may be negligible. Some roof coating distributors recommend re-coating after ten years because of a rapid decrease in albedo after the tenth year. A roof surfaced with coating #3 fifteen years earlier had an albedo of 0.3.

The albedo of most roofs was restored to initial values by washing. Calculations showed, however, that washing a high-albedo coating only to achieve energy savings is presently not cost-effective. Thus, resistance to dust and soot is an important consideration in choosing a high-albedo coating.

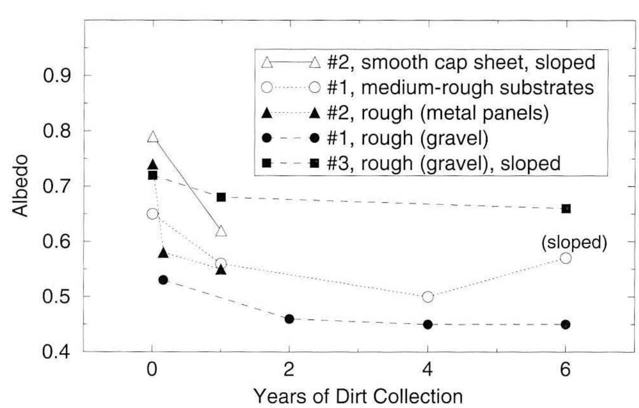

Figure. *Albedo vs. age for three roof coatings on different substrates.*

Remote Sensing for Urban Heat-Island Analysis

K.H. Orvis, X. Liu, H. Akbari

The summertime urban heat-island phenomenon, while well understood in the general case, necessarily varies in specifics from one city to another. Causative factors such as albedo depression and diminished vegetation cover are far more easily analyzed in a synoptic view than on the ground. Remote sensing offers a cost-effective method of estimating these and other aspects of the urban fabric of individual cities so that planners can identify the particular mitigation strategies that would be most cost-effective for their city, and even to identify subregions (neighborhoods or zoning categories) that could most benefit.

Standard remote-sensing approaches assume the analyst will use an essentially visual approach. Numerical methods—especially in resource management fields but even in more rigorous fields such as geology—are used primarily as a means of making evident the landscape patterns of import to the analyst, which she or he is then expected to interpret. In studying urban heat island phenomena, however, our goal is numerical analysis of physical parameters: albedo, surface temperature, and certain flux ratios.

Consequently, we have developed a series of modeling capabilities that allow the retrieval of accurate surface fluxes from remotely sensed data. In particular, we have concentrated on the ability to model conditions so that field measurements do not have to be made at the same time the remote sensing instrument is acquiring the data. Such an ability vastly reduces the overhead required for analysis, since it means any archived imagery can be used. Archived imagery is often free; single-purpose NASA flights cost several thousand dollars per hour.

Analysis of albedo and other factors that involve surface reflection requires a knowledge of downwelling flux (hemispheric insolation) to compare with the upwelling fluxes measured by the remote sensing device. Downwelling fluxes vary with time and location and with atmospheric conditions; California summer atmospheres produce markedly different effects than do more typical temperate-latitude atmospheres. We have used the Air Force Geophysics Laboratory's LOWTRAN-7 atmospheric radiation-modeling program, with actual atmospheric parameters at the time of data acquisition, to model downwelling flux. LOWTRAN does not itself model global insolation, so we have developed general software to calculate, from multiple LOWTRAN runs, both narrow-band (sensor-specific) and full-spectrum hemispheric insolation. This software also calculates differential insolation across uneven terrain (Figure) so that lighting artifacts are avoided.

Atmospheric effects differ from one segment of the spectrum to another. Consequently, we use LOWTRAN to model the fate of upwelling light on the way to the sensor in each of an arbitrary sensor's narrow "bands," across the range of scan angles that contribute to the sensed image, as well as the downwelling narrow-band and full-spectrum fluxes. In this way, any remote sensor can be used to best advantage to calculate full-spectrum albedo as well as reflectance in narrower segments of the spectrum. Finally, we apply similar techniques to thermal-band fluxes, allowing as accurate an assessment of surface temperatures as possible.

With this suite of capabilities in hand, we can calculate in a straightforward manner the actual fluxes of interest to investigators of summer urban heat islands. We are now in the process of putting together a package of manuals and software, which will put these capabilities within easy reach of analysts.

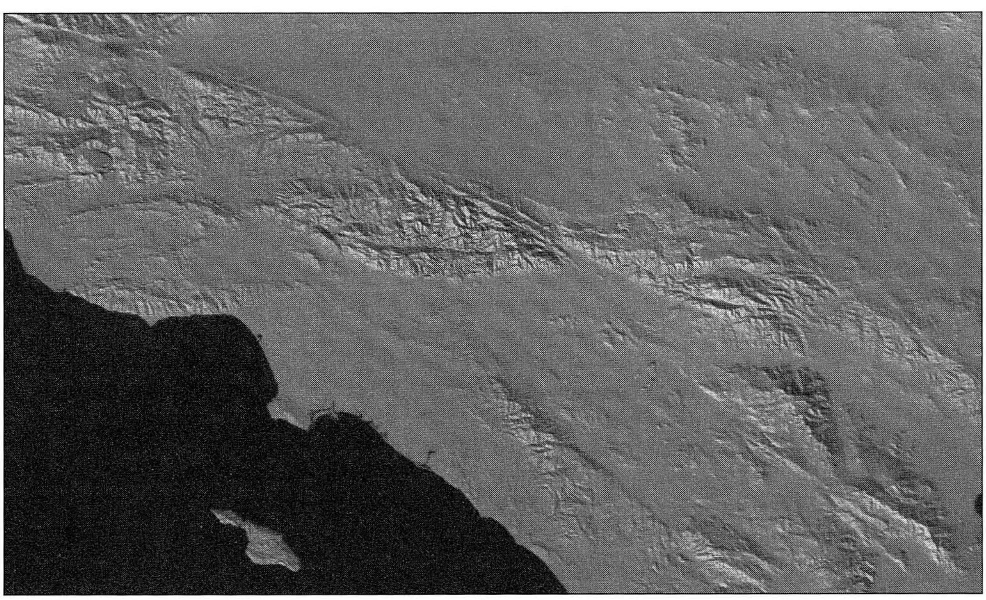

Figure. *Analysis of relative insolation, 250-meter digital elevation model (DEM) grid of California's South Coast Air Quality Management District meteorological-modeling domain, calculated for the time of a NOAA-11 satellite overpass, October 18, 1991. Water surfaces are rendered in black to help orient the viewer. Scale: 325 x 200 km.*

Fire Safety and Building Energy Efficiency Aspects of Reflective Coatings

P. Berdahl

The purpose of this exploratory project was to evaluate the feasibility of developing new, practical materials that can retard the spread of fire due to enhanced reflectivity of infrared radiation emitted by fire. A second purpose was to evaluate the relationship between materials that reflect fire radiation and those used for energy efficiency. Examples of coatings for energy efficiency are white coatings for keeping buildings cool and low-emissivity (low-E) coatings for reducing heat losses through windows.

A quantitative understanding of the radiant energy transfers due to fire, sunlight, and ordinary thermal radiation requires an examination of the relevant spectra. The Figure shows typical spectral distributions of these radiant flows on a logarithmic scale by wavelength in micrometers. Based on the Figure, we can conclude that if a building is to be kept cool, the exterior surface should be reflective at short wavelengths and should switch to absorptive (and, by Kirchhoff's law, emissive) in the 5-10 μm range. If a building is to be kept warm, it should be absorptive at short wavelengths, and switch to reflective in the 1-2 micrometer range. In this way it can be reflective in either case in most of the spectrum of fire radiation.

The most important technical result of the project was the identification of pigments that can be used in coatings to reflect the infrared radiation from fire. First, already existing aluminum pigments can be used. Second, conventional white pigment materials can be used, but only if the particle size of the pigment is greatly increased—from about 200 nm to 1-2 μm. Computer simulation of light scattering from small particles was used to confirm these findings. The absorptance of coated-wood substrates of fire radiation can be reduced from the usual values of about 70% to below 20%, which has the potential to slow the rate of spread of fire to wooden structures. An industrial partner is now being sought to help commercialize this new technology.

One conclusion of this study is that, due to the overlap of the fire spectrum with both the solar and 300 K thermal spectra, fire retardant coatings can either enhance or impair energy performance. From a research and development point of view, there is considerable synergism between coating technologies for improved energy efficiency and for improved fire safety. Developing technology for improved energy efficiency can be adapted to coatings for reflecting fire radiation, and vice versa.

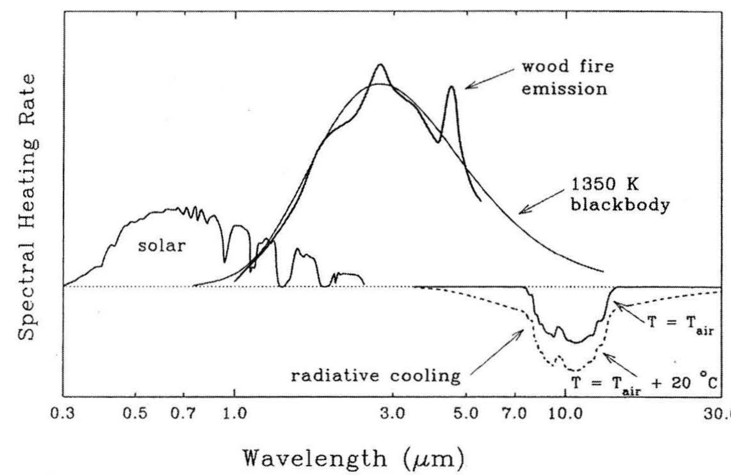

Figure. *Spectral distribution of radiant energy from sunlight (solar), from a wood fire (which is similar to a 1350 K blackbody), and from the radiative cooling effect. The spectrum of radiant cooling is for a horizontal surface facing the sky, when the surface temperature is equal to air temperature, and when the surface temperature is 20 °C above air temperature.*

End-Use Forecasting

The Potential for Efficiency Improvements in Residential and Commercial Buildings

J.G. Koomey, R.E. Brown, C.S. Atkinson

A 1991 LBL report assessed the technical potential for improving the efficiency of electricity use in the U.S. residential sector. This potential is expressed in terms of cost and electricity savings. The results for a given year are presented in a supply curve of conserved electricity, which has total electricity savings (Terawatt-hours or TWh) on the x-axis and cost of conserved energy (cents/kWh) on the y-axis.

The supply curve consists of roughly 300 energy-conservation measures, which fall into four distinct categories:

- retrofitting existing building shells;
- improving the thermal performance of new building shells;
- raising the efficiency of equipment and appliances as they are replaced;
- switching from electricity to natural gas.

Because of the sophistication with which building shells and equipment are analyzed, the vast majority of the conservation measures affect energy use in space conditioning. The conservation supply-curves framework is somewhat more detailed than the REEPS model (see the following article) in characterizing building shell technologies.

This year, LBL forecasting researchers attempted to compensate for some of the limitations of the technical potential framework by adding factors to account for real-world constraints on program implementation, for program and administrative costs, and for other effects that limit potential energy savings (including the persistence of savings and the "take-back" effect). Figure 1 shows our assessment of the achievable potential and the importance of the different factors that affect the technical potential, and Figure 2 shows how the technical potential and achievable potential estimates are related.

Reference

Brown RE. *Estimates of the Achievable Potential for Electricity Efficiency in U.S. Residences.* M.S. Thesis, Energy and Resources Group, University of California, Berkeley. Lawrence Berkeley Laboratory Report No. LBL-34835, 1993.

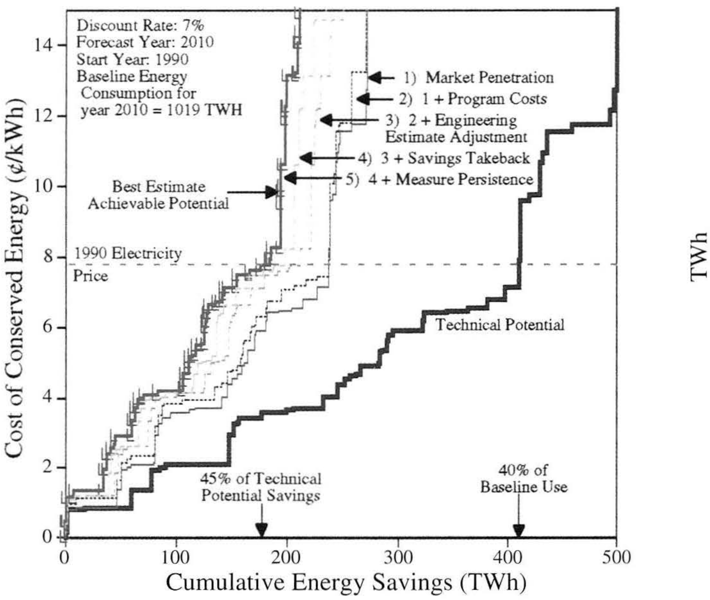

Figure 1. *Supply curves of conserved electricity. Each step represents a conservation measure. The height of each step is the measure's cost of conserved energy (cents/kWh); width is the estimated savings potential for that measure in the year 2010. To characterize more accurately the experience with real policies and programs, the achievable potential curve includes corrections to the technical potential curve.*

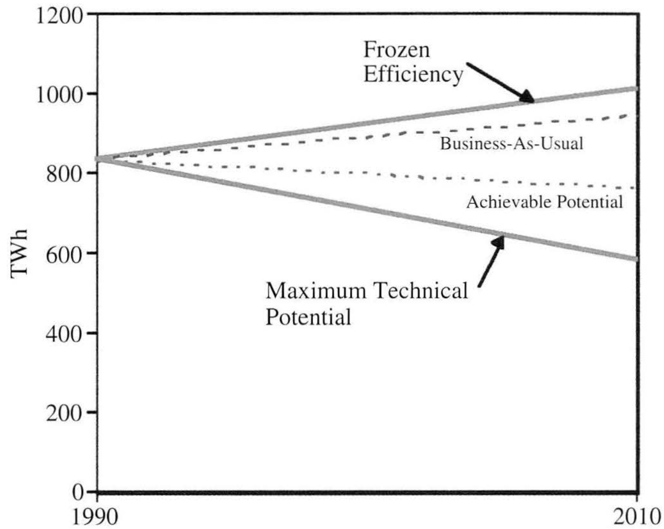

Figure 2. *Electricity use over time for the baseline (frozen efficiency) forecast, a business-as-usual forecast, the achievable conservation potential, and the technical potential.*

Residential Data and Forecasting

J.G. Koomey, R.E. Brown, F. X. Johnson, J.W. Hanford, R.J. Hwang, M.E. Lecar, L. Stewart, J.E. McMahon, M.D. Levine

The purpose of this activity is to compile, document, and analyze data used in forecasting models and to store them in a computerized form that is easily accessible to researchers. These data include unit energy consumptions for 12 end uses compiled from 65 studies, historical appliance shipments, historical appliance saturations, historical shipment-weighted efficiencies, thermal shell characteristics of buildings, cost versus efficiency relationships for appliances and building shells, and summaries of all current appliance efficiency standards for every end use affected by the standards.

In the past, deciphering the methods and sources used to derive input data for forecasting models has been difficult or impossible. To address this problem, all information in the database is fully documented with the source and an explanation of how it was derived. This data-compilation project has advanced the state-of-the-art and allowed DOE and others easy access to LBL's extensive residential data.

The information from the database is used in computer models that forecast residential sector energy use. These models rely upon empirically derived cost-efficiency relationships, fuel price and housing projections, and other parameters that characterize the way consumers choose the efficiency of their appliances and equipment. The models are a convenient way to organize and manipulate the detailed data necessary for assessing the effects of polices at the end-use level.

We use the Electric Power Research Institute's REEPS model, a modeling system widely used by forecasters in the electric utility industry. It is extremely flexible, allowing the user to change functional relationships without having to change the underlying computer code. We currently have a national model, as well as models that explicitly represent heating and cooling for northern and southern climates. The input data for the residential forecasting model are documented in the references.

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Hanford JW, Stewart LE, Lecar ME, Johnson FX, Hwang RJ, Koomey JG. Baseline Data for the Residential Sector and Development of a Residential Forecasting Database. Lawrence Berkeley Laboratory Report No. LBL-33717, 1993.

Johnson FX, Hanford JW, Sanstad AH, Koomey JG. *HVAC Data, Assumptions, and Methodology for Residential End-Use Forecasting with EPRI-REEPS 2.1.* Lawrence Berkeley Laboratory Report No. LBL-34045, 1993.

Hwang RJ, Johnson FX, Hanford JW, Koomey JG, Brown, RE. Appliance *Data, Assumptions, and Methodology for Residential End-Use Forecasting with EPRI-REEPS 2.1.* Lawrence Berkeley Laboratory Report No. LBL-34046, 1993.

Commercial Data and Forecasting

J.G. Koomey, A.O. Sezgen, E. Franconi, S. Greenberg, H. Akbari, J.E. McMahon, M.D. Levine

Data and modeling are less advanced in the commercial sector than in the residential sector. This is true in part because of the heterogeneity of the commercial sector compared to the residential sector, in part because of the greater complexity of commercial buildings, and in part because most utility and government programs were first implemented for residences (and therefore estimates of the impacts of these policies were first developed for residences).

In the commercial sector, we rely on EPRI's COMMEND modeling framework. Because COMMEND is not currently as flexible as REEPS, (see previous article) LBL is working with its designers to improve the accuracy and usefulness for policy analysis.

COMMEND is capable of analyzing 11 building types and 10 end uses. We have revised the default data for lighting in all the building types using data compiled at LBL. We have also revised the heating, ventilation, and air-conditioning (HVAC) data for two of the building types (large and small offices) using prototypes developed from DOE's Energy Information Administration 1989 *Commercial Building Energy Consumption Survey* (CBECS) and other sources.

Data development is continuing for the commercial sector with the medium-term goals of 1) completing revisions for HVAC data in all remaining building types and for office equipment, refrigeration, and water heating in all building types, and 2) creating an internally documented commercial forecasting database analogous to that for the residential sector.

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Sezgen AO, Huang YJ, Atkinson BA, Koomey JG, *Technology Data Characterizing Lighting in Commercial Buildings: Application to End-Use Forecasting with COMMEND 4.0.* Lawrence Berkeley Laboratory Report No. LBL-34243, 1993.

Consumer Behavior/Market Failures

A.H. Sanstad, J.G. Koomey, M.D. Levine

Researchers have been investigating the nature of consumers' decision-making and the problems of market imperfections for energy efficiency. These issues have long been the focus of debate in both policy and academic circles. Understanding them is fundamental to assessing correctly the effects of different policies on energy use and societal welfare.

Our work critically surveys two decades of research on consumer energy use, contrasting behavioral, engineering, and economic views of consumer behavior. Each approach provides different answers to fundamental questions about energy demand and policy, bringing forward the concept of "bounded rationality" as a vehicle for partial integration of these disparate perspectives.

One approach to providing an analytic formulation of bounded rationality is the so-called "prospect theory" developed by behavioral decision theorists. We developed a version of this type of model, incorporating an intertemporal dimension, and applied it to the problem of consumer investments in energy efficiency, particularly the interpretation of high implicit discount rates for such investments. The key component of this model is a "value function" measuring consumer evaluations of gains and losses associated with efficiency investments in terms of deviations from a reference point (Figure). Analysis using this behavioral model demonstrates how these high rates could arise from systematic deviations from cost minimization on the part of consumers. The work also explores the implications of this finding for assessments of the benefits and costs of minimum energy efficiency standards.

Another focus of this work has been the economic analysis of energy efficiency and energy policy. We find that basic economic principles combined with extensive empirical evidence provide a strong case for the existence of market imperfections related to energy efficiency. These principles, combined with the empirical evidence, also point toward policies intended to correct these imperfections.

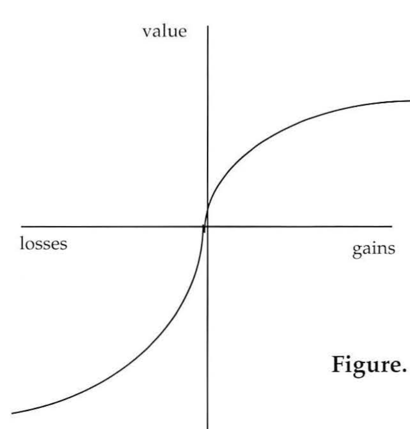

Figure. *A hypothetical value function.*

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Sanstad AH. *Consumer Energy Research: A Critical Survey.* Lawrence Berkeley Laboratory Report No. LBL-33555, 1993.

Sanstad AH. *On Consumer Rationality and Energy Demand: Some Simple Analytics of Loss Aversion in Efficiency Choice.* Lawrence Berkeley Laboratory Report No. LBL-34777, 1993.

Sanstad AH, Howarth RB. *"Normal" Markets, Market Imperfections, and Energy Efficiency.* Paper presented at the 15th Annual North American Conference of the International Association for Energy Economics, Seattle, WA, October 10-13, 1993.

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Energy Conservation Policy

Analysis of Federal Appliance Efficiency Standards

J.E. McMahon, B. Atkinson, S. Boghosian, P. Chan, T. Chan, J.G. Koomey, M.E. Lecar, M.D. Levine, J. Lutz, G. Rosenquist, A.O. Sezgen, S. Stoft, I. Turiel, C. Wodley

The Energy Policy and Conservation Act (P.L. 94-163), as amended by the National Energy Conservation Policy Act (P.L. 95-619) and by the National Appliance Energy Conservation Act of 1987 (P.L. 100-12) and by the National Appliance Energy Conservation Amendments of 1988 (P.L. 100-357), provides energy-conservation standards for 12 of 13 types of consumer products* and authorizes the Secretary of Energy to prescribe amended or new energy standards. The Energy Policy Act of 1992 (P.L. 102-486) adds five products: (14) general-service fluorescent lamps and incandescent reflector lamps, (15) shower heads, (16) faucets, (17) water closets, and (18) urinals, for which test procedures and labels will be developed. This Act sets standard levels for lamps, motors, commercial heating and cooling equipment, and commercial water heaters, and includes a schedule for possible amendments to the standards.

Initiated in 1979, LBL's assessment of the standards is designed to evaluate their economic impacts according to the legislated criteria (Figure).

The economic impact analysis is performed in five major areas:

- *Engineering Analysis*, which establishes the technical feasibility and product attributes including costs of design options to improve appliance efficiency.
- *Consumer Analysis* at two levels: national aggregate impacts (forecasts) and impacts on individuals (life-cycle cost analysis). The national aggregate impacts include forecasts of appliance sales, efficiencies, energy use, and consumer expenditures. The individual impacts are analyzed by life-cycle cost, payback periods, and cost of conserved energy, which evaluate the savings in operating expenses relative to increases in purchase price.
- *Manufacturer Analysis*, which provides an estimate of manufacturers' response to the proposed standards. Their response is quantified by changes in several measures of financial performance.
- *Utility Analysis*, which measures the impacts of the altered energy-consumption patterns on electric utilities.
- *Environmental Analysis*, which estimates changes in emissions of carbon dioxide, sulfur oxides, and nitrogen oxides resulting from reduced energy consumption in the home and at the power plant.

This year, based on our analysis, DOE continued to consider possible updated standards for eight products: room air conditioners, water heaters, mobile home furnaces, direct heating equipment, kitchen ranges and ovens, pool heaters, televisions, and fluorescent-light ballasts. Data collection and analysis continued for possible updated stand-ards for refrigerators and freezers, central air conditioners, and heat pumps and furnaces.

In the next year, we will continue the analysis of possible energy efficiency standards for the eleven products listed above.

The Energy Policy Act of 1992 expands the appliance efficiency program at DOE to include lamps, motors, commercial heating and cooling, and commer-cial water heating. We will perform analyses of some or all of these products, as directed by DOE in 1994.

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U.S. Department of Energy, Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Codes and Standards.

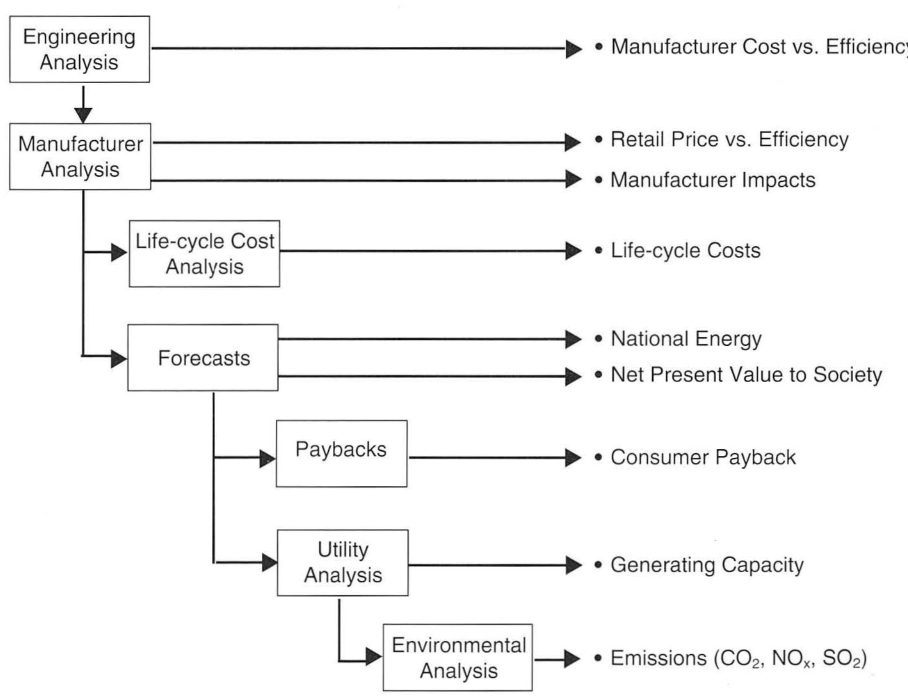

Figure. *Analytic framework for the appliance standards analysis.*

*Products covered: refrigerators, refrigerator-freezers, and freezers; room air conditioners; central air conditioners and heat pumps; water heaters; furnaces; dishwashers; clothes washers; clothes dryers; direct heating equipment; kitchen ranges and ovens; pool heaters; television sets; and fluorescent-lamp ballasts.

Technical Support Document: Energy Efficiency Standards for Consumer Products: Room Air Conditioners, Water Heaters, Direct Heating Equipment, Mobile Home Furnaces, Kitchen Ranges and Ovens, Pool Heaters, Fluorescent Lamp Ballasts, and Television Sets. Report No. DOE/EE-0009. Washington, D.C.: U.S. Department of Energy, 1993.

Turiel I, McMahon JE, Lebot B. Global residential appliance standards. In: *The Energy Efficiency Challenge for Europe, Proceedings of the European Council for an Energy-Efficient Economy Summer Study, June 1-5, 1993,* Vol. 1. Rungstedgård, Denmark: European Council for an Energy-Efficient Economy, 1993, p. 183.

Engineering Analyses of Appliance Efficiency Improvements

I. Turiel, B. Atkinson, S. Boghosian, J. Lutz, G. Rosenquist

The economic impacts of appliance efficiency standards depend largely on the relation between cost and energy consumption of a consumer product. Our engineering analysis seeks to identify this cost-consumption relation for selected appliances.

In 1993 we completed engineering analyses for three products: central furnaces and boilers, refrigerators and freezers, and central air conditioners and heat pumps. This work involved extensive meetings with industry and government task force working groups.

The engineering analysis consists of the following steps: select appliance classes; select baseline units for each class; select design options for each class; and determine the maximum technologically feasible design, the efficiency improvement, and the cost for each option for each class. Data are obtained through contacts with trade organizations and manufacturers, from suppliers of purchased parts and materials, and from computer simulations.

In 1994 we plan to write the technical support documentation for the engineering analysis of three products: central heating, central air conditioning and heat pumps, and refrigerators and freezers. We will respond to comments on an advance notice of proposed rule-making on the three products. We will also respond to comments and revise our report on the analysis of eight products (water heaters, pool heaters, direct heating equipment, mobile home heaters, fluorescent ballasts, room air conditioners, ranges/ovens, and televisions), after receiving review comments.

Reference

U.S. Office of the Federal Registrar. *Energy Conservation Program for Consumer Products: Advance Notice of Proposed Rulemaking Regarding Conservation Standards for Three Types of Consumer Products; Proposed Rule.* September 8, 1993, p. 47326. *10 CFR Part 430.*

Assessing the Impacts of Appliance Standards on Manufacturers

T. Chan, S. Stoft

The Manufacturer Analysis assesses the impact of appliance standards on the profitability and competitiveness of the various appliance-manufacturing industries affected by mandatory energy efficiency standards. The primary tool used for this evaluation is the Manufacturer Impact Model (LBL-MIM). LBL-MIM uses engineering cost and efficiency estimates as well as collected economic and financial data as inputs. Outputs include price, rate of profit, shipments, revenues, net income, and the standard errors of these estimates. LBL-MIM also provides estimates of retail prices used by the Residential Energy Model (LBL-REM) and the life-cycle cost analysis.

This year we used the LBL-MIM to perform an analysis of the impact of standards on water heaters, direct heating equipment, room air conditioners, kitchen ranges and ovens, pool heaters, mobile home furnaces, televisions, and fluorescent lamp ballasts. The results are contained in a technical support document published by the U.S. Department of Energy.

We wrote the manufacturer impact section of a report submitted to DOE on the impacts of federal policies to improve the energy efficiency of lighting in U.S. commercial and residential buildings. Our analysis indicates that the diverse policy options available would not have significant adverse impacts on lighting equipment manufacturers.

Data collection and preliminary analysis for the next round of products were also begun. The products considered include refrigerators and freezers, central heating equipment (furnaces and boilers), and central air conditioners and heat pumps. We have submitted questionnaires to firms, including associations and industry consultants, evaluated the data received, and prepared to generate retail prices for the next steps in the analysis process.

We have also reviewed an alternative analytical model for the manufacturer analysis, specifically the Government Regulatory Impact Model (GRIM). GRIM was a joint effort between several industry trade associations (Association of Home Appliance Manufacturers, Gas Appliance Manufacturers Association, and Air Conditioning and Refrigeration Institute), and the consulting firm, Arthur D. Little. We have developed a proposed method for modifying the LBL-MIM to include GRIM for the cost analysis but without displacing industry return on equity as the primary impact variable.

In 1994 we expect to analyze public comments on the initial eight-product analysis, begin a re-analysis of the eight-product analysis based on those comments and any new data that may be received, complete a preliminary analysis of the next three products, and begin initial efforts for the next round of products, which will include clothes washers and dryers, and dishwashers.

Reference

U.S. Department of Energy, Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Codes and Standards. *Technical Support Document: Energy Efficiency Standards for Consumer Products: Room Air Conditioners, Water Heaters, Direct Heating Equipment, Mobile Home Furnaces, Kitchen Ranges and Ovens, Pool Heaters, Fluorescent Lamp Ballasts, and Television Sets.* Report No. DOE/EE-0009. Washington, D.C.: U.S. Department of Energy, 1993.

The LPROGNOS Model: Government Policies for Energy-Efficient Indoor Lighting in the Netherlands

B. Atkinson, J. Jennings, K. Lo, J.E. McMahon

We developed the spreadsheet model LPROGNOS (lighting prognosis) to assess energy and economic impacts of lighting technology and to estimate policy alternatives for a project entitled Government Policies for Energy-Efficient Indoor Lighting in the Netherlands. Commissioned by the Netherlands Agency for Energy and the Environment on behalf of the Ministry of Economic Affairs of the Netherlands, the project was conducted by Bakkenist Management Consultants with the assistance of LBL's Energy Conservation Policy Group.

LPROGNOS is a flexible analysis tool that forecasts energy consumption and costs for lighting under a variety of policy scenarios. Using basic data for a country or geographic region, LPROGNOS projects baseline lighting consumption for a period of years. Annual energy consumption (kWh/year) is calculated as the product of lighting power density* (W/ft^2 or m^2), annual operating hours, and floor space (ft^2 or m^2). Indoor lighting is characterized by technology and building sector (e.g., offices, other non-residential, industrial, and residential). More detailed disaggregation (e.g., by building type) is possible where data permit. LPROGNOS calculates the relative contribution from different technologies, including incandescent, fluorescent, compact fluorescent, and high-intensity discharge lamps and ballasts, within each building sector. The effects of lighting controls are also included.

The model is composed of linked spreadsheets including Basic Assumptions, Technology Database, Engineering/Economics Spreadsheets, and Forecasting Model. Technology data include price and energy consumption for typical and energy-efficient alternatives such as efficient lamps, ballasts, and controls. Operating hours and floor space are specified for each building sector. For future years, market shares of lighting technologies are specified by the user.

Alternative lighting policies are programmed into the Forecasting Model. Each policy is evaluated in terms of energy savings, costs (technology and program costs), expenditures for energy, net present value, and ratio of benefits to costs.

In the Netherlands, the model has been successfully applied to a diverse set of policies such as ballast standards, designer incentives, consumer information, and rebates. In 1994 we will complete the Netherlands lighting policy analysis.

*Weighted-average lighting power density for all lighting technologies.

Reference

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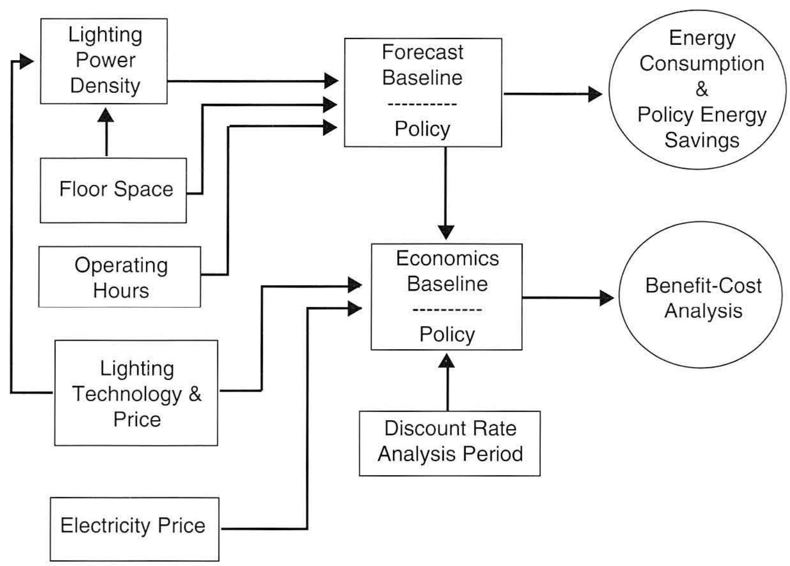

Figure. *Flowchart of LPROGNOS forecasting model.*

Utility Planning and Policy

Integrated Resource Planning for Gas Utilities

C.A. Goldman, G.A. Comnes, J.F. Busch, S. Wiel

Integrated resource planning (IRP) is a process used by utilities to assess a comprehensive set of supply- and demand-side resource options to create a resource mix that reliably satisfies customers' energy service needs at the lowest total cost. While electric utilities have used IRP in many states, most state public utility commissions (PUCs) are only now beginning to consider its use for gas utilities. Consideration of gas IRP by PUCs is driven by 1) the goal of meeting customers' needs in an environmentally acceptable manner, 2) the ongoing restructuring in the natural gas industry that—as a result of the creation of transportation-only pipeline services and the unbundling of other utility services—is requiring PUCs to re-evaluate the process by which they regulate gas utilities, and 3) the perception that in some instances IRP in the electric industry requires coordination with resource planning in the gas utility. Interest in gas IRP is underscored by the 1992 Energy Policy Act, which requires PUCs to consider IRP for gas utilities. Because of the interest in gas IRP by PUCs, the Energy Conservation Committee of the National Association of Regulatory Utility Commissioners asked the Utility Planning and Policy Group at LBL to prepare a *Primer on Gas Integrated Resource Planning*.

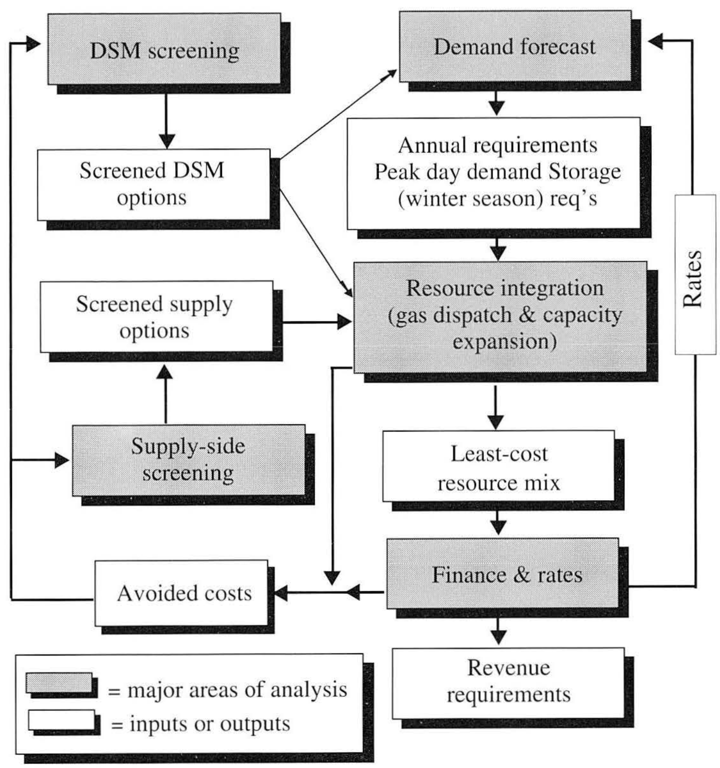

Figure. *Analytic framework for gas IRP.*

The *Primer* discusses the rationale for gas IRP and alternative business and regulatory structures through which gas IRP could be implemented (e.g., strategic planning processes internal to the gas utility, a comprehensive regulatory proceeding, or parallel regulatory proceedings that address demand-side management (DSM) and supply-side issues separately). Regardless of the regulatory structure, several areas of analysis must be coordinated: demand forecasting, demand-side and supply-side screening, resource integration, and financial and rate planning. A simplified representation of the analysis framework and the relationships between various areas is shown (Figure). The *Primer* addresses six major technical and policy issues.

Gas Utility Supply and Capacity Planning. As a result of ongoing restructuring in the natural gas industry, gas utilities can no longer rely on regulated upstream suppliers to manage their portfolio of gas contracts, storage facilities, and pipeline resources. In light of these changes, the *Primer* provides an overview of resource options, planning methods, and issues associated with the acquisition of gas supplies and facilities that provide adequate deliverability. The *Primer* also discusses alternative regulatory frameworks for the review of gas supply portfolios including pre-approval and mechanisms for regulating incentives.

Methods for Estimating Avoided Gas Costs. Avoided costs are a crucial link in the IRP process because they provide the standard by which DSM and incremental supply-side resources are evaluated. The *Primer* describes and compares four methods for calculating avoided gas costs: system marginal cost, a generic proxy approach, a targeted marginal approach, and average-cost methods. Strengths and weaknesses of each method are described and there is a discussion of key issues that arise in estimating gas avoided costs: recognition of uncertainty (especially uncertainty associated with future commodity costs) and how new resources established as a result of recent federal regulatory actions (such as pipeline capacity-release programs) affect the modeling of avoided costs.

Economic Analysis of DSM Programs. The economic analysis of DSM measures or programs relies heavily on the results of benefit-cost tests that attempt to capture program impacts from the perspective of different affected parties (e.g., participating customers, non-participating customers, utilities, and society). The *Primer* describes how to compute standard benefit-cost tests for efficiency and fuel-substitution programs and discusses key technical and policy issues that arise in the application of the tests.

Assessing Gas DSM Potential. Assessing the magnitude and cost of DSM resources is an important activity, in part because it provides utilities with information on one of the underlying rationales for IRP: whether there are significant quantities of cost-effective DSM resources that can be captured by utility DSM programs. The *Primer* reviews the results of recent gas DSM potential studies and provides technical information on individual gas equipment-efficiency measures and strategies that are applicable to the residential and commercial sectors. The *Primer* also reviews key issues involved in designing, implementing, and evaluating gas DSM programs.

End-Use Fuel Substitution. Fuel-substitution programs are utility DSM programs that promote the substitution of one fuel source for another for a particular end use. These programs have been controversial, in part because of ongoing competition among the electric, natural gas, and unregulated fuel industries for market share in the space-conditioning, water-heating, cooking, and drying equipment markets. The *Primer* primarily focuses on end-use fuel-substitution opportunities between electricity and natural gas and discusses key policy issues and alternative regulatory approaches that PUCs can take to address fuel substitution.

Financial Aspects of Gas DSM. Significant disincentives may exist under traditional rate regulation that dampen utilities' enthusiasm to pursue energy efficiency opportunities. Such disincentives can include the failure of gas utilities to recover DSM program costs, the negative financial impact on gas utility earnings because of reduced sales, and the loss of financial opportunities because the utility may forego more profitable supply-side investments. The *Primer* discusses various strategies that can mitigate the disincentives to utilities for sponsoring DSM programs including improved cost-recovery mechanisms, net lost revenue-adjustment mechanisms, revenue-decoupling mechanisms, and positive financial incentives for shareholders (e.g., shared savings programs). The *Primer* also discusses general methods for allocating authorized DSM program costs among classes of retail customers.

Reference

Goldman CA, Comnes GA, Busch JF, Wiel S. *Primer on Gas Integrated Resource Planning.* Prepared for the National Association of Regulatory Utility Commissioners. Lawrence Berkeley Laboratory Report No. LBL-34144, 1993.

The Theory and Practice of Decoupling

J. Eto, S. Stoft, T. Belden

Alfred Kahn once said all regulation is incentive regulation. Nowhere is the challenge embodied in this observation greater than in the current debates on regulatory reforms in support of integrated resource planning (IRP). IRP requires that a utility consider all resource options for meeting customers' energy service needs in a consistent fashion. For demand-side management (DSM) options in particular, questions have been raised about the appropriateness of traditional utility rate regulation for aligning the earnings incentives of utilities with the goals of IRP.

For several years, Lawrence Berkeley Laboratory has been involved in evaluating emerging regulatory ratemaking reforms that encourage a utility to promote DSM. In 1993, we completed a detailed examination of the theory and practice of decoupling. Decoupling refers to a class of ratemaking procedures that ensure collection of an agreed-upon level of revenues independent of actual sales. Without decoupling, a utility may lose revenue from sales not made due to the success of customer energy efficiency programs.

Our work addresses three issues: 1) Why decouple? 2) How does decoupling work? 3) What have been the rate impacts of decoupling?

Stated simply, there is an incentive for a utility to sell additional electricity whenever marginal revenues exceed marginal costs. Between rate cases, since prices are fixed by definition (i.e., marginal revenue equals average revenue), profitability is determined by the cost structure of the utility. We demonstrate analytically how profitability, between rate cases, depends on: 1) the initial level of profitability (prior to the incremental sales), 2) the fraction of total costs affected by the production expenses incurred to make the incremental sales (i.e., the variable cost fraction), and 3) the degree to which these costs are affected (relative to average variable costs). In doing so, we provide a framework for assessing various specific claims of profitability (e.g., a 1% increase in sales leads to additional basis points in return on equity).

We turn next to the specific operation of decoupling mechanisms. We observe that the critical distinction between traditional ratemaking and decoupling is that while traditional ratemaking focuses on rate setting, decoupling shifts the emphasis of ratemaking to revenue setting. In doing so, decoupling requires explicit consideration of the means by which revenues are set during the period between rate cases. We develop formal expressions that describe the price-setting mechanics of traditional ratemaking and those of both current forms of decoupling, the Electric Revenue Adjustment Mechanism (ERAM), as practiced in California, and the related Revenue Decoupling Mechanism (RDM)—used by several New York utilities including Orange and Rockland, Consolidated Edison, Long Island Lighting Company, New York State Electric and Gas, Rochester Gas and Electric, and Niagara Mohawk Power Company—and the Revenue-Per-Customer approach (RPC), as practiced by Central Maine Power and Puget Power in Washington.

In the final section of the report, we examine the effect that decoupling has had on rate volatility and risk shifting with a detailed review of the actual rate history of the utilities with the longest history of decoupling: Pacific Gas and Electric, Southern California Edison, and San Diego Gas and Electric. We find that for most California utilities, decoupling has actually reduced rate volatility compared to a situation in which, with modest caveats, there is no decoupling. Decoupling can in principle add to or counteract other sources of rate volatility and in California, the net effect has been one of offsetting these other sources. Assessing the rate impacts of ERAM along with the other influences on rates also provides a basis for commenting on the magnitude of risk shifting accounted for by ERAM. The record in California suggests that the risk shifting accounted for by ERAM is, in fact, dwarfed by that accounted for by the fuel-adjustment clause (Figure).

We conclude that decoupling can play an important role in moving utilities from sellers of a least-cost energy commodity to providers of least-cost energy services, but it is no panacea. Instead, careful consideration of the strengths and limitations of decoupling in the context of an existing system of regulation is critical for comparing the benefits of decoupling with other ratemaking reforms.

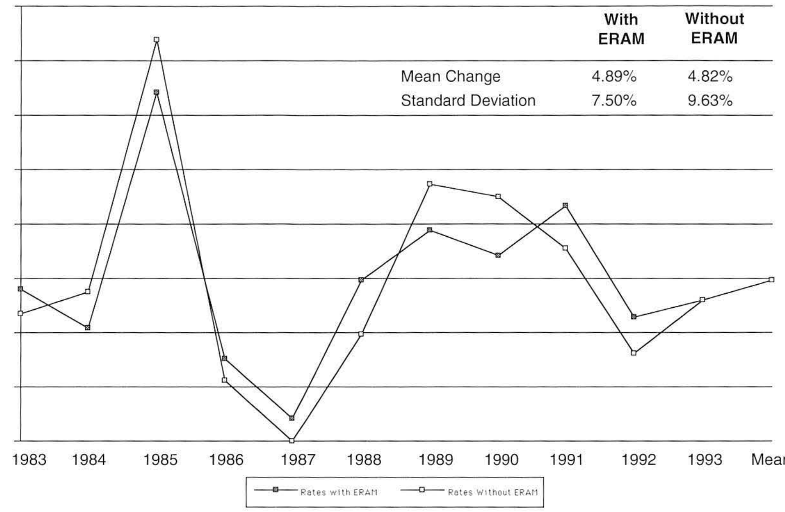

Figure. *Decoupling rate impacts for the Pacific Gas & Electric Company.*

Reference

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Economics of Demand-Side Bidding Programs

C.A. Goldman, S. Kito

Beginning in December 1987, U.S. utilities began experimenting with various approaches that allowed energy service companies (ESCOs) and customers to propose projects in competitive bidding solicitations. As of October 1993, approximately 25 utilities had conducted bidding programs in which demand-side management (DSM) projects were eligible. About 1500 megawatts (MWs) of DSM projects were proposed and utilities selected 175 DSM bids representing more than 425 MWs.

DSM bidding programs represent an interesting phenomenon. First, because they typically involve payment for delivered savings over relatively long periods, DSM bidding programs provide information on the ESCO industry's price for providing guaranteed "negawatts." Second, DSM bidding programs allocate risks associated with DSM resources in an explicit fashion between ESCOs, customers, and utility ratepayers. In more conventional utility-sponsored DSM programs, these risks are often born implicitly by ratepayers. Third, given the limitations and quality of data, utilities and regulators need to devote additional resources to collecting all relevant information on program costs and to monitoring long-term savings.

In 1993, our work focused on the subset of programs in which utilities have selected winning bidders and information is available on program costs. The Table summarizes the results from each utility program. In order to compare contracts among different utilities and with varying payment streams, a common nominal discount rate of 11% was used to calculate levelized costs in cents/kWh. Major findings are:

- Demand reductions contracted for by various utilities under their DSM bidding programs range from 6 to 55 MWs. ESCOs—rather than customer bidders—dominate the DSM bidding market, accounting for 86% of the demand reductions. In most bidding programs, utilities have awarded several contracts, typically two to seven, to ESCOs. In the few instances where individual contracts have been signed, there have either been many customer bidders (e.g., Public Service of Colorado) or the utility was a co-signer to each individual energy service agreement signed between an ESCO and host customer (e.g., Boston Edison).
- Total resource costs range from 5.4 to 8.0 cents/kWh among the seven DSM bidding programs for which data are available. Based on a comparison of total resource costs as a percent of the utility's avoided supply costs at the time the Request for Proposals (RFP) was issued, several on these programs appear to be only marginally cost-effective from a societal perspective. Estimates of future avoided costs have decreased significantly (20-30%) at many of these utilities since the RFPs were issued, primarily because of reduced need for new capacity and forecasts of lower future gas prices.
- Average payments to winning bidders vary significantly among utilities, ranging from 1.5 to 7.5 cents/kWh. Factors that appear to contribute to differences in bid prices among individual projects and utility programs include: 1) differences in the allowed ceiling prices of DSM bids among utilities, 2) maturity of the energy services industry, 3) perceived competitors, which may be related to the type and size of solicitation, 4) differences in the mix of measures, services offered, and market sectors targeted by DSM bidders, 5) the degree to which performance risks are borne by DSM bidders, which is related to payment provisions and performance guarantees, and 6) the extent to which bidders attempt to recover project costs from host customers directly.
- Differences in ceiling prices among utilities appear to be the dominant factor that accounts for the variation in

average bid prices across utilities. Ceiling prices appear to be particularly important in the early DSM bidding programs when experience with DSM bidding was lacking and the energy services industry was relatively immature. As the industry matures, one would expect bid prices to decrease because of increasing competition and possibly lower perceived risks among more experienced bidders. Looking at average bid prices over time and bid prices as percent of ceiling price, there is some evidence to suggest that increased competition among DSM bidders is putting downward pressure on prices. For example, in the most recent bidding programs in California, bid prices were about 60% of the utility's ceiling price compared to initial programs in which bid prices were typically between 75-90% of the utility's ceiling price. DSM bid prices also vary because bidders target different market segments and offer varying mixes of measures and services. For example, bids targeting residential customers average 6.2 cents/kWh compared to 4.9 cents/kWh for commercial/industrial bids. Slightly less than 90% of the contracted demand reduction is targeted at commercial/industrial facilities, while about 10% is aimed at residential customers.

Reference

Goldman CA, Kito, S. *Review of Utility Experience with DSM Bidding.* Lawrence Berkeley Laboratory Report No. LBL-35021, 1993.

Table. *Economics of DSM bidding programs.*

Utility*	Program Size (MW)	No. Contracts Analyzed	TRC (¢/kWh)	TRC as % of Avoided Cost	Bid Price (¢/kWh)	Bid Price as % of Ceiling Price
New England Electrical System	17	3	-	-	3.54-6.12	-
Boston Edison Company	9	84	-	-	5.30	88
Central Maine Power #1	17	6	-	-	5.83-6.05	85-88
Central Maine Power #2	36	4	-	-	5.63-5.98	86-91
Orange & Rockland Utilities-NY	10	4	7.45	82	1. 48	81
Orange & Rockland Utilities-NJ	6	4	6.53	77	6.35	75
Puget Sound Power & Light	10a	5	-	-	4.90	-
Jersey Central Power & Light	10	2	8.01	90	7.50	84
Public Service Electric & Gas	39	7	7.14	104	5.74	83
Niagara Mohawk Power Company	20	5	5.41	57	3.76	39
Long Island Lighting Company	7	2	-	-	3.01	86
Consolidated Edison	6	2	5.59	42	4.24	77
New York Electric & Gas	9	6	-	-	4.50	46
Rochester Gas & Electric	17	2	-	-	4.20	77
Public Service of Colorado #1	55	32	-	-	2.72	-
Sacramento Municipal Utilities District	6	2	-	-	3.22	66
Pacific Gas & Electric	14	7	5.42	65	4.88	59
Public Service of Colorado #2	52	45	-	-	2.83	-

*Utility programs are ordered chronologically (the most recent programs appear at bottom).
TRC = total resource cost

The Price of Electricity from Private Power Producers

E. Kahn

The introduction of competition into long-term wholesale electricity markets will change the regulatory process. Regulators will increasingly have to judge the reasonableness of the prices paid to wholesale electricity suppliers. However, this kind of price regulation (as opposed to cost of service regulation) needs developed data-collection procedures to be successful. No generally accepted standardized form currently exists in which the long-term prices paid to non-utility generators are expressed.

The behavior of prices in the private power market also has important implications for integrated resource planning. These prices will increasingly take on the role of a value standard for utility investments and demand-side management programs. Both planners and regulators need to have some measure of value based on alternative opportunities. Administrative estimates of avoided cost have played the role of a value standard in planning. As market price formation becomes better developed and more familiar, it is reasonable to expect that avoided cost will be gradually replaced by a market price standard.

This analysis systematically compares the prices of a small sample of recent private power projects. Information about price is derived primarily from the contracts between the utility and the private power producer. The contracts are typically available from the public utilities commissions in the various states. The project sample is summarized (Table, next page).

We compute the levelized cost of electricity as a function of the capacity factor. This results in each project being represented by a price curve. We adopt this approach because the projects we examine are all contractually obligated to pro-

Table. *Sample of supply contracts between utilities and private power producers.*

Name	Buyer	Seller	Date Executed	Contract Length	Start Date (Proposed)	Size (MW)
Brooklyn Navy Yard A	Consolidated Edison Co. of New York	Mission Energy & York Research	10/91	32 yr, 8 mo	May 1992	40
Brooklyn Navy Yard B	Consolidated Edison Co. of New York	Mission Energy & York Research	10/91	30 yr, 8 mo	May 1994	40
Brooklyn Navy Yard Central	Consolidated Edison Co. of New York	Mission Energy & York Research	10/91	30 yr, 8 mo	May 1994	90
Dartmouth	Commonwealth Electric Co.	Energy Management, Inc.	9/89	25 yr	May1992	67.6
Doswell	Virginia Electric . & Power Co.	Diamond Energy	6/87	25 yr	Dec 1991	600
Holtsville	Long Island Lighting Co.	Power Authority of State of New York	12/91	20 yr	May 1994	136
Pedricktown	Atlantic City Electric Co.	Cogeneration Partners of America	4/88	30 yr	Feb 1992	106
Wallkill	Orange & Rockland Utilities, Inc.	U.S. Generating Co.	6/90	20 yr	April 1994	95
Chambers	Atlantic City Electric Co.	U.S. Generating Co.	9/88	30 yr	Oct 1993	184
Crown-Vista	Jersey Central Power &Light	Mission Energy & Fluor Daniel	4/90	20 yr	June 1994	100
Indiantown	Florida Power & . Light Co.	U.S. Generating Co.	5/90	30 yr	Dec 1995	300

vide the purchasers with "dispatchability" privileges. This means that output from the projects can be varied (frequently within certain contractual limits) as the value of power fluctuates. Dispatchability requirements are becoming increasingly common in power purchase contracts and can be expected to continue as a feature of the private power market.

The contract lengths vary from 20 years to approximately 33 years. Prices have been levelized over the duration of the contract and no attempt has been made to adjust for the different contract lengths, i.e., the "end effects" issues.

All payment streams have been discounted to the start of commercial operation. To compare projects with different start dates, prices have been inflated or deflated to mid-1992.

We present the results of our calculations for a low gas-price forecast, where we assume that gas commodity prices will rise at 5.1% per annum (inflation plus 1%). The cost curves for each of these projects are illustrated (Figure). Some price curves cross one another. Such crossings show the necessity for representation of the complete curve, rather than collapsing price into a one-dimensional measure. There is no way to know *ex ante* whether such crossings would occur.

The results do not show that the "law of one price" is operative in this market yet. The projects divide roughly into high-, low-, and medium-priced groups. The high-priced projects are Holtsville, Dartmouth, Indiantown, Pedricktown, and Chambers. Doswell, Brooklyn Navy Yard Central, and Wallkill are the low-priced group. Crown-Vista and the other two Brooklyn Navy Yard projects are in the middle of the range.

The average price of the gas-fired

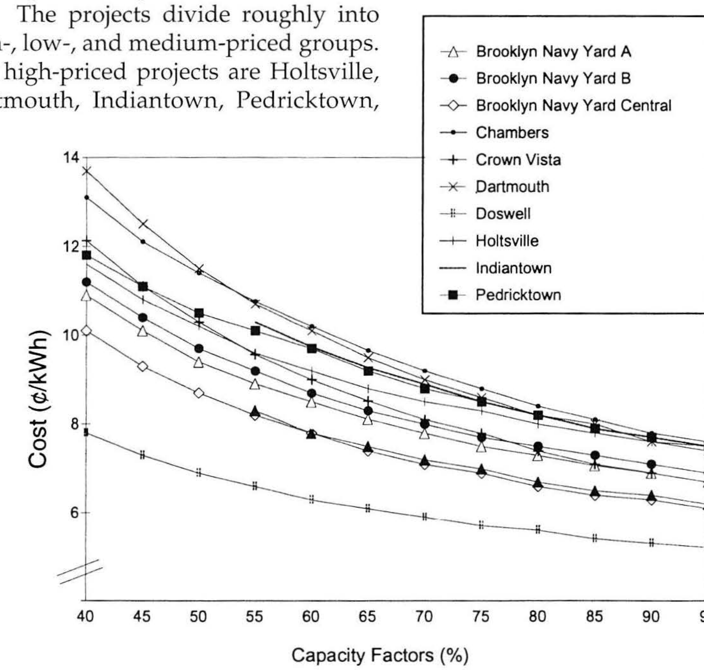

Figure. *Contract prices at various capacity factors (with low gas price forecast).*

projects (unweighted by capacity) for 85% capacity factor is 7.0 cents/kWh at low gas prices and 7.4 cents/kWh at high gas prices. The high-price scenario increases price by 0.5-0.7 cents/kWh for the five projects that have fuel prices indexed to the gas spot market. The coal projects average 7.7 cents/kWh. The variation among the gas projects is much greater than among the coal projects.

Because fixed-price components play a large role in the cost structure of all of these projects, the spread of prices is greater at lower capacity factor than at higher capacity factor. The unbundling of gas prices contributes to the similarity in price structure of solid-fuel and gas-fired projects; i.e., both project types have very substantial fixed cost components, regardless of actual production.

These levelized cost calculations should be interpreted with some caution because some unresolved issues remain. There are substantial uncertainties associated with the gas prices used in our calculations. A more thorough investigation of the indices in these projects, verifying their performance in the interval between contract signing and this analysis, might result in some downward adjustments to the price estimates.

More importantly, we have not yet developed a methodology for comparing costs across contracts with different lengths. Projects that operate more hours or for longer terms generally provide more value (or net benefits) to the utility. One way to correct for this "end effects" problem would be to determine the utilities next best source of electricity at the end of the contract term and to incorporate the price for the alternative source into the shorter duration contracts.

The ultimate purpose of this work is to explain the observed variation in prices that emerge from this analysis. Some of the factors relevant to such a model would include cost differences (scale and geography) and market characteristics.

Reference

Kahn E, Milne A, Kito S. *The Price of Electricity from Private Power Producers.* Lawrence Berkeley Laboratory Report No. LBL-34578, 1993.

The LBL Advanced IRP Seminar

J. Eto, J. Busch, C. Goldman, E. Kahn, G.A. Comnes

Technology transfer is a central aspect of Lawrence Berkeley Laboratory's Integrated Resource Planning (IRP) project. Review of utility IRP filings by state utility regulatory commissions presents new challenges for commissions because many IRP concepts, especially those related to demand-side management (DSM), are unfamiliar. At the request of the National Association of Regulatory Utility Commissioners, the project designed a seminar on leading IRP issues for state commission staffs who must review utility IRP filings.

In 1993, we held the third LBL Advanced IRP Seminar. The seminar, attended by 22 utility regulatory commission staff members representing 20 state commissions, included staff from 6 state commissions that had not participated in previous LBL seminars. In total, 66 regulatory staff, representing 37 state commissions, have now participated in at least one of the three seminars.

The week-long seminar consisted of four types of activities: 1) lectures by experts on "core" IRP issues such as IRP plan guidelines, DSM programs, and avoided costs; 2) software exercises that examined selected aspects of these issues; 3) topical lectures on emerging IRP issues, such as ratemaking reform, Clean Air Act compliance, renewables, and gas IRP; and 4) informal sessions, such as a tour of the Pacific Gas & Electric Company (PG&E) Energy Center.

At the end of the week, each participant was asked to evaluate each component of the seminar. A scale of 1 to 4 was used, with 4 being the top rating. As in previous years, the overall seminar was rated significantly higher (3.9) than any individual component of the seminar. Among the "core" IRP issues, the descriptions of DSM program designs (3.6), the guidelines for a "good" IRP (3.6), and the discussion of integration methods (3.5) were rated highest. The software exercises were ranked nearly equally (3.2 or 3.3). Among the topical lectures, the discussions of ratemaking reforms for DSM, linking incentives to DSM evaluation, implications of the Clean Air Act for IRP, and gas IRP were rated highest (all at 3.5). Of the informal sessions, the PG&E Energy Center tour was most well-received (3.6); the course materials (3.8) and the seminar location (3.7) were also highly rated.

Global Energy/Environmental Issues

Energy Efficiency and Air Quality in the South Coast Air Basin

H. Taha, X. Liu, D. Sailor, A. Meier, M.D. Levine, A. Winer, S. Douglas†, J. Haney†*

The objective of this project is to quantify the positive and negative impacts of large-scale increases in albedo and vegetation on the meteorology and air quality in the South Coast Air Basin (SoCAB). A three-dimensional mesoscale model is run to provide meteorological input to the photochemical Urban Airshed Model (UAM) to analyze the effects of surface modifications on SoCAB's ozone air quality. Areas where albedo or vegetation increases are feasible were identified through extensive land-use categorization coupled with aircraft measurements and satellite imagery. A low-altitude aircraft was flown explicitly for the purpose of characterizing the surface properties, mainly albedo, of SoCAB.‡ Several albedo- and vegetation-modification scenarios, and combinations thereof, were simulated with the meteorological model and UAM to quantify their consequences in terms of ozone air quality. The meteorological simulations indicate that it is possible to cool significant areas in SoCAB by as much as 3 °C by increasing the surface albedo or vegetative cover in urbanized areas by an average of 0.20. While such temperature depressions are beneficial in reducing cooling energy use, it remains to be seen whether these depressions and related changes in the meteorological fields have small or no negative impacts on ozone air quality.

Our standalone sensitivity simulations with UAM indicate that reducing the domain-wide near-surface temperature by 2 °C results in decreases in ozone of up to 35 parts per billion (ppb) at 3 P.M. during a selected summer oxidant episode when the range of baseline concentrations over the domain is from 50 to 225 ppb. A decrease in the mixed layer depth, resulting from the near-surface cooling induced by albedo and vegetation, can have both positive and negative impacts on ozone concentrations, depending on location, emissions, temperature, terrain, and wind-flow patterns. A domain-wide decrease of 25% in the mixing height results in increases of up to 20 ppb and decreases of up to 45 ppb in some areas of SoCAB.

In preliminary comprehensive meteorological and photochemical simulations, UAM was run to simulate a case of increased albedo in the urbanized areas of SoCAB. The average level of increase was 0.15 and was mostly concentrated in the western basin. The Figure shows a difference plot for ozone concentrations between the high-albedo case and the base case. Following increases in albedo, some areas in SoCAB receive higher ozone concentrations whereas others have lower concentrations. But for the time interval depicted in the Figure, there was a net domain-wide decrease of ~100 tons of ozone in the lowest layer (breathing level). Extensive simulations will be performed in FY 1994 to gain detailed insight into these results and determine whether increasing albedo is beneficial or detrimental in terms of ozone air quality.

The simulations for the effects of vegetation are currently being prepared. They will account for the positive effects of increased vegetation (lower air temperatures and larger pollutant uptake) as well as the negative ones (increased biogenic emissions). Combined, comprehensive simulations for albedo and vegetation modifications will identify the net impact on air quality.

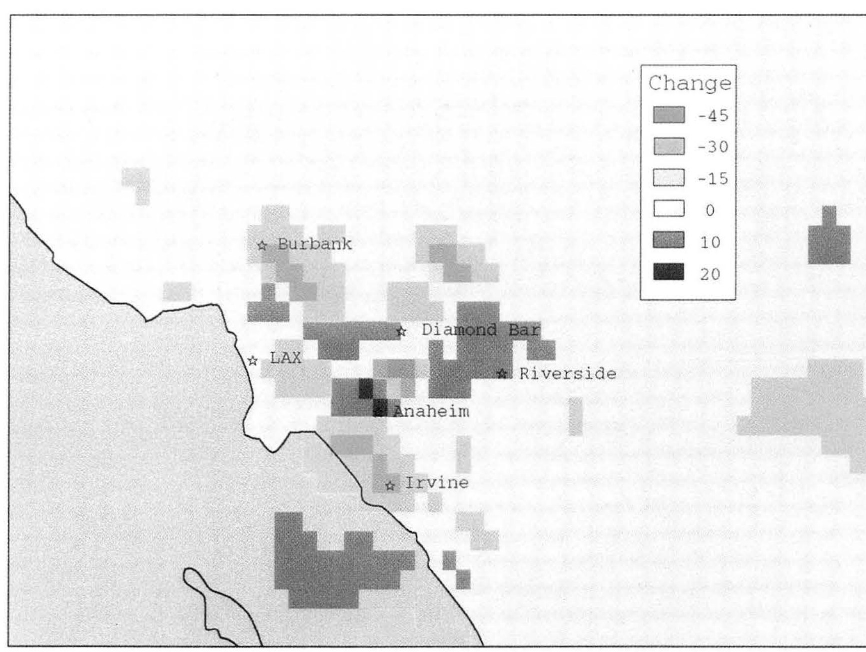

Figure. *Difference in near-surface ozone concentrations (ppb) between the base case and a case where urban albedo in SoCAB has been moderately increased (average increase = 0.15). Blue areas are improvements in air quality, whereas the darker (grey) ones represent an increase in ozone concentrations following the albedo modifications. Shown at 3 P.M. on August 27, 1987.*

*University of California, Los Angeles, CA.
†Systems Applications International, San Rafael, CA.
‡Low-altitude aircraft measurements are useful in calibrating high-altitude, remote-sensing data gathered from satellite platforms or from NASA's high-altitude aircraft.

Assessing Oceans as CO_2 Sinks

R.L. Ritschard, K.H. Orvis, P.J. Neale

Critical uncertainties remain in our understanding of global biogeochemical cycling, particularly the carbon budget. Of the total estimated release of carbon dioxide (CO_2) due to fossil-fuel burning and changing land use, less than half is now present in the atmosphere. The oceans are believed to be taking up much of the remainder at a rate of about 2 gigatons/yr. What is not known, however, is how this capacity is regulated. CO_2 is the principal greenhouse gas and little disagreement exists about the amounts being released into the atmosphere. However, we remain unable to account for all the CO_2 that is leaving the atmosphere and going into either terrestrial or oceanic sinks.

Oceanic primary productivity, especially the "new production" balanced by precipitation from ocean surface waters, is an important component of the global carbon budget. Recent high-resolution measurements of variation in atmospheric oxygen have suggested that global oceanic new production may be at least twice as high as had been previously calculated based on estimates of ^{14}C uptake by marine phytoplankton. Knowledge of ocean and ocean-margin dynamics is essential to our ability to observe, analyze, and finally predict the early, subtle response of climate to gradual increases in atmospheric greenhouse gas concentrations.

A project was begun in FY 1992 to investigate several research topics related to the fate of CO_2 in the oceans. During 1993, study focused on laboratory investigations of the relationship between quantum yield of fluorescence and carbon fixation for the purpose of developing direct methods to remotely sense chlorophyll activity (i.e., primary production) in oceans, and on modeling atmospheric extinction and scattering at wavelengths critical to remote sensing of marine phytopigments in order to improve quantitative remote estimates of phytoplankton productivity. To address the latter topic, we compared Coastal Zone Color Scanner (CZCS) satellite imagery to measured levels of chlorophyll concentrations off the Southern California coast.

Satellite-based and aircraft-based remote sensing instruments yield the only possible synoptic views of inherently dynamic aquatic systems. They cover large areas cheaply, and satellites especially can retrieve data from remote regions easily and regularly. Sensing phytopigment signatures from space involves first the recovery, from light arriving at the spacecraft, of the original brightness of the light as it left the ocean surface. Since sunlight scattered upward by the atmosphere is typically an order of magnitude stronger than the attenuated ocean signal, accurate correction for atmospheric effects is difficult to achieve. Furthermore, pigment estimation algorithms are sensitive to small changes in ratios between measurements in different parts of the spectrum.

Standard correction methods have been developed for the simplest common atmospheric conditions: a clean marine-aerosol boundary layer overlain by average tropospheric conditions, with the sun at a small zenith angle. Under these conditions, the ratio of atmospheric path radiance within the phytopigment bands to atmospheric path radiance within a reference band is known and nearly constant. West Coast atmospheric conditions, especially during offshore airflow events, often differ strongly from the marine standard (Figure). We have modeled a variety of West Coast conditions and are also analyzing effects of multiple scattering at large solar zenith angles. Results have been tested with archived CZCS satellite imagery and will be validated with California Cooperative Fisheries data and other surface measurements. These findings are pertinent in other regions and will also prepare us for meeting the new accuracy standards of NASA's SeaWiFS satellite, particularly in West Coast waters.

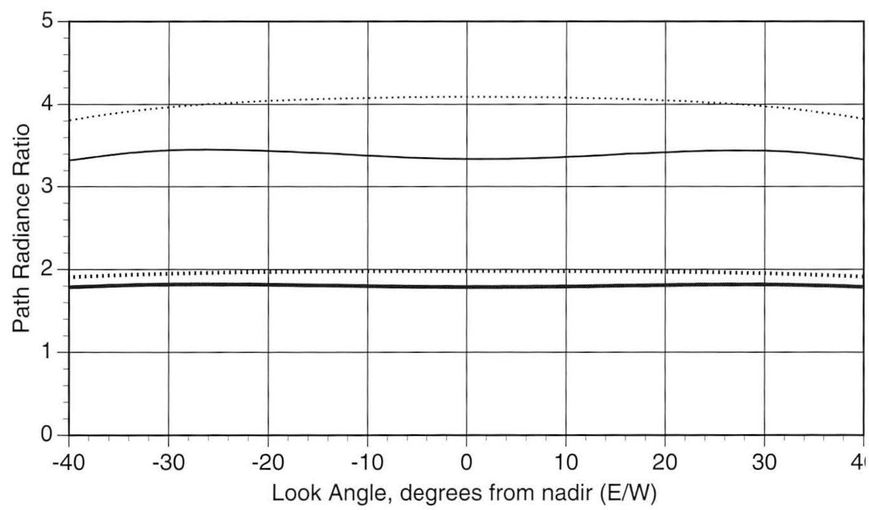

Figure. *Comparison of atmospheric path radiance ratios between signal bands (CZCS 1 and 3) and the reference band (4) given contrasting atmospheric aerosol regimes in the lower 2 km of the atmosphere. "Marine" is the marine standard; "Urban" is a California summer atmosphere laced with urban aerosols, typical of vortex conditions over the Southern California Bight. Since these ratios form the basis of atmospheric correction, any deviation from the standard marine case will result in phytoplankton estimation errors.*

Using Output from a General Circulation Model to Generate "$2 \times CO_2$" Weather Tapes for DOE-2 Hourly Simulations

H. Taha, R. Ritschard

As part of the ongoing research into the potential effects of global climate change, the scientific community has been interested in forecasting the impacts of such changes, if they occur, on energy use at regional (system-wide) and small (building) scales. One potential method for studying and quantifying these impacts involves using the DOE-2 simulation program with modified weather tapes (i.e., at "$2 \times CO_2$") for comparison with simulations performed with current TMY weather data. Relevant meteorological variables that would differ between the $1 \times CO_2$ and $2 \times CO_2$ cases include air temperature, cloud cover, solar radiation, precipitation, and atmospheric moisture, each of which may change by different proportions. Thus, the objective in this project is to improve the estimate of the impact of global climate change on future energy use by accounting for the space- and time variations in these variables. And since the DOE-2 program is an hourly model, it would be desirable to account for hourly variations in the weather variables.

For this project, we obtained from the Goddard Institute for Space Studies (GISS) 6-hourly output from their General Circulation Model (GCM) for $1 \times CO_2$ (~present) and $2 \times CO_2$ (~2040) scenarios at a resolution of 4° by 5°. We focused on the U.S. portion of the output, although the methods we developed can be used for any other location. A program was written to fetch data from the GISS GCM output (corresponding to a user-specified location or grid cell), manipulate them, and compute the differences for each variable at 6-hour intervals between the $1 \times CO_2$ and $2 \times CO_2$ cases. A smoothing function is then applied to derive hourly differences in the meteorological fields from the 6-hourly data. These hourly differences are then merged onto existing TMY weather tapes to generate $2 \times CO_2$-TMY hourly weather tapes that can be used by the DOE-2 program to simulate future patterns of energy use (Figure). The next step in this work will involve using mesoscale meteorological models to fine-tune the GISS GCM output by performing sub-grid-scale meteorological simulations for areas where higher spatial resolution is needed, e.g., urbanized areas.

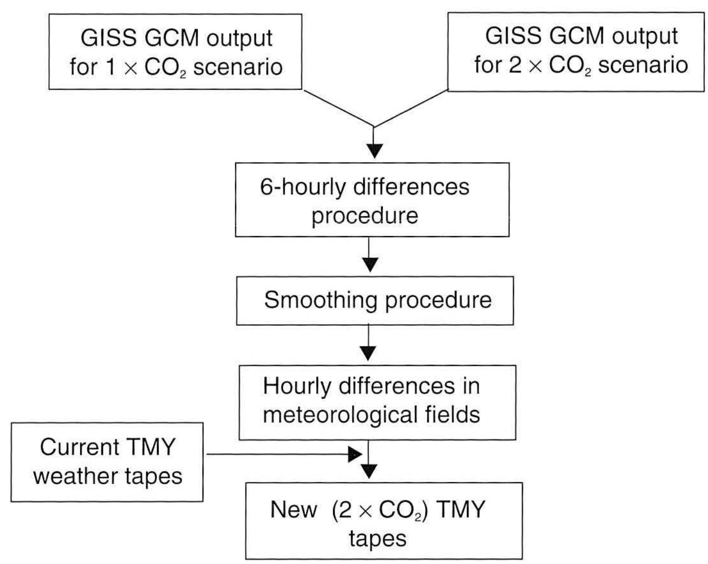

Figure. *Flowchart showing the main components of the weather tape generation process.*

The Developing Countries Network on the Environmental Impacts of Global Climate Change

K.L. Nelson, R.L. Ritschard

The Developing Countries Network on the Environmental Impacts of Global Climate Change was initiated by Lawrence Berkeley Laboratory in order to facilitate and encourage the implementation of impact studies in developing countries. At present, the Network consists of nine scientists representing as many countries: Bangladesh, Brazil, China, India, the Republic of the Marshall Islands, Mexico, Thailand, Vietnam, and Zimbabwe.

During the first year, we selected the Network countries and representatives, determined which impacts of climate change are of critical importance to each Network country, and identified the existing in-country resources for implementing a research project focusing on one or more of these issues. The representatives perceived some common trends among the issues identified as top priorities.

The most common issues of concern are changes in land use and urban air pollution. Other issues listed by several countries as top priorities include water quality, the need for improved energy efficiency, biodiversity, and the availability of renewable energy resources. It appears that the issues of primary concern to the developing countries in the Network are not simply the issues that may be affected by future global climate change; they are also issues that are of immediate concern. An assessment of these issues may contribute to changes that will improve a country's current environmental situation, in addition to reducing its vulnerability to climate change.

We have identified each country's existing resources that could be used to research the issues of critical importance. These resources include published reports, data, methodologies, and models that have been developed or used, current research projects, research facilities, and organizations. Some participating countries have already completed country- or issue-specific impact studies. Almost all of the countries have completed comprehensive environmental reports that identify areas for further research.

We have also identified the necessary non-existent resources Almost all of the Network countries identified a lack of financial support, an inadequate institutional framework, and insufficient data. Some countries also identified a lack of applicable or appropriate mitigation options, an insufficient number of trained personnel, and a lack of adequate research tools as problems. With regard to the last two problems, a definite role is suggested for the Network: that of providing training programs and the transfer of appropriate analytical tools. The Network, by providing a framework for collaborative work, can also provide support to help overcome the other problems.

Depending on funding for FY 1994, the Network plans to initiate research activities. A workshop for all Network members will be held that will use the information identified during the first year as a focal point. After reviewing this information, we will choose specific issues on which to focus our research, determine what resources are needed in order to conduct research, develop a common methodology, determine where collaboration is possible (e.g., extrapolation of data, data analysis, sharing of equipment, and personnel), and organize training workshops if needed.

The China Project: Energy Efficiency and Policy Studies

M.D. Levine, F. Yang, J. Sinton, X. Xi, N. Martin

The Energy Analysis Program's China Project is an ongoing effort to analyze various energy policies in China in collaboration with Chinese energy planners and researchers. The project's goals are:

- to gain knowledge about energy efficiency opportunities in China and to encourage implementation;
- to establish close working relationships with colleagues in China;
- to work with Chinese energy experts to improve energy efficiency programs and investments; and
- to assist the progressive elements of the energy community in China to design and carry out needed reforms in the energy sector.

Since its establishment in 1988, the project has produced 20 publications, hosted several visiting Chinese scholars and delegations, and established strong relationships with Chinese colleagues. An important theme of its published work has been to make widely known that China has invested substantial funds in energy efficiency, and that these investments have contributed significantly to a large decrease in the energy intensity of China's economy. Among the project's most important publications is the *China Energy Databook,* an invaluable guide to energy production, consumption, investment, and other statistics that was compiled in association with Chinese colleagues. In the past year, the project has completed a state-of-the-art assessment of energy efficiency opportunities in buildings in China (which could serve as a basis for new energy efficiency policies in China), and a rigorous analysis that shows that the major cause of recent energy intensity reductions in Chinese industry is a combination of falling physical intensity and other factors operating within industrial subsectors, and not structural change, as the Chinese policy community has long held. Most recently, the Program has become a founder of the Beijing Energy Efficiency Center (BECon), a center dedicated to the advancement of energy efficiency policies and technologies. The China Project work is headed by Dr. Mark Levine with staffing currently consisting of two Chinese scientists, a graduate research assistant, and other staff as needed.

In the past, much of the project's research focused on identifying energy efficiency opportunities in the Chinese building and industrial sectors and in analyzing policy issues related to reforming energy supply and use. The industrial intensity and efficiency studies have included the iron and steel, cement, electricity, and chemical subsectors. Future research topics include the potential for cogeneration, further analysis of past energy conservation investments, as well as construction of an energy conservation supply curve to aid in setting future conservation investment priorities. A series of case studies of energy use behavior at individual industrial enterprises will be key to designing effective strategies for implementing conservation policies. The project will provide technical support for integrated resource planning (IRP) efforts, and for market assessments of energy-efficient technologies (lighting, motors, and refrigerators).

The project has become a key point of transfer and exchange of technical expertise between Chinese and U.S. energy policymakers and researchers. Counting only those who stayed at least two months, the project has already hosted 10 visiting Chinese researchers at LBL for 36 person-months. The project has also hosted official delegations and study tours on various energy and environmental topics. In October 1992, the China Project hosted a conference, *Energy, Environment, and Market Mechanisms in China,* which has led to important follow-up work. One outcome of these visits and exchanges has been to stimulate the interest of top planners in IRP, leading to initiation of a highly significant IRP project in Shenzhen, China's most successful Special Economic Zone and a model for the rest of the country. These face-to-face interactions are a crucial element of the strong foundation needed for long-term cooperative research efforts. The following five articles provide more detailed summaries of the project's ongoing work.

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Energy Conservation in China During the Seventh Five-Year Plan

Z. Liu, F. Yang, M. Ting, J.E. Sinton

Energy-conservation investment programs administered by China's central government during the Seventh Five-Year Plan (1986-1990) continued the work of improving the industrial energy efficiency begun in 1980. Between 1986 and 1990, 30.8 Mtce/yr* of new energy-conservation capacity was installed. Significant overall economic improvements in energy efficiency as well as in individual industrial processes occurred concurrently with the conservation programs. Energy intensity of GDP decreased at an annual rate of 2.48% from 1.05 to 0.93 kgce/yuan (real) between 1985 and 1990. Table 1 shows the changes in seven types of the most energy-intensive products during the period.

In cooperation with the Energy Research Institute of China's State Planning Commission, the China Project reviewed the formulation and implementation of energy-conservation policies during the Seventh Five-Year Plan, performed simple cost-benefit analyses of investment programs, and described the energy-conservation potential in major industrial sectors.

During the last half of the 1980s, the Chinese central government issued sets of energy-conservation regulations, including more than 400 energy efficiency standards. The promulgation of the first comprehensive national legislation for energy conservation, entitled "Provisional Regulations for Energy Management," reflected the priority placed on conservation. The government established six regional training centers and 200 technical training sites which trained more than 30,000 enterprise managers.

While emphasizing conservation, the central government also withdrew from its role as the primary funding source for conservation investments. Instead, it provides about one third of the total funds, with local governments and enterprises required to provide the rest. Direct allocation of capital has been phased out and replaced with low-interest loans at rates of 3% or less. The types of projects that receive the most interest are "rational heat utilization," i.e., promotion of more efficient boilers and industrial furnaces, waste heat recovery, cogeneration, district heating, and recovery of gaseous byproducts that have fuel value. Some projects have multiple objectives and strive to reduce the use of materials such as steel and feedstock inputs.

Table 2 shows unit investments in energy conservation for various projects. All the figures are below the unit investment in energy development in the late 1980s, about 1000 yuan/tce-yr, including mining, processing, and transportation. (These numbers account for inflation; those for conservation investments do not, so the difference between supply and conservation-capacity cost may be greater than indicated.) Over the last decade, the unit investment in energy conservation was about one third that of energy-supply development. Energy-conservation programs appear to have tapped an important low-cost supply of energy services at a time when energy sources and capital for investment were in short supply. Because most conservation projects also contributed to increases in profitability, productivity, and improvements in product quality, ranking them only in terms of energy conservation may be misleading. Indeed, the criteria for project selection included qualitative consideration of environmental benefits during the Seventh Five-Year Plan.

Judging by the large difference in average cost between energy conservation and energy supply, a great deal of economically attractive conservation capacity was not exploited. Energy-conservation investments accounted for only 1% of total capital construction investment. One important cause may have been distorted energy prices, which were much lower than market value, so that many enterprises perceived little benefit in conservation. Very inefficient equipment continued to be used, especially at small enterprises, since energy costs were felt to be unimportant, and the benefits not large enough to warrant the risks in adopting new, more efficient technologies. Invest-

Table 1. *Unit energy consumption for seven major industrial products, 1985-1990.*

Product	Unit	1985	1990	Change (%)
Electricity, coal-fired plants (>6,000 kW)	gce/kWh	431	427	0.9
Steel (total energy)	kgce/ton	1,746	1,611	7.7
Aluminum (large plants)	kWh/ton	15,047	14,916	0.09
Ammomia (large plants)	kgce/ton	1,368	1,343	1.8
Ammonia (medium plants)	kgce/ton	2,236	2,176	2.7
Ammonia (small plants)	kgce/ton	2,358	2,254	4.4
Cement (large plants)	kgce/ton	210	201	4.3
Caustic soda	kgce/ton	1,581	1,527	3.4
Calcium carbide (large plants)	kgce/ton	2,031	1,921	5.4

Table 2. *Unit investment in capital construction projects, 1986-1990.*

Project	Total Investment (million yuan)	Energy Savings (million tce-yr)	Unit Cost of Savings (yuan/tce-yr)
Cogeneration	7,168	9.91	723
Generator replacement	86	0.27	319
Small chemical plants	127	0.45	279
Small cement plants	40	0.12	574
Emitted fuel-gas	1,207	3.22	375
Central heating	747	1.66	450
Honeycombed briquette	217	1.26	172

*Because coal is the dominant fuel in China, units are presented in terms of standard coal equivalent. One metric ton of standard coal equivalent (tce) equals 29.31 GJ (low heat) or 5.147 barrels of oil equivalent. Other common units are grams, kilograms, million tons, and gigatons of standard coal equivalent (gce, kgce, Mtce, and Gtce, respectively).

ment-evaluation methods that have been used for choosing energy-conservation projects were thought to be simple, but proved inappropriate or difficult to use. New methods of energy-conservation evaluation must be developed.

Chinese planners expect energy intensity to continue decreasing at an annual rate of 2.4 to 3%. Energy-conservation programs will emphasize electricity and oil savings, rational utilization of heat energy, and the promotion of greaterefficiencies in key production processes and end-use equipment. State loans and investment in this decade will help establish demonstration projects for advanced technologies. International technical cooperation and investment funds are expected to be increasingly important for continued declines in energy intensity.

Further work in this area will focus on developing improved methods for evaluating the results of energy-conservation investment programs. Equally important will be assessing the relative effectiveness of investment programs with other policy tools, such as efficiency standards, technical assistance, and price rationalization.

Energy Intensity in Chinese Industry

J.E. Sinton, M.D. Levine

Since the initiation of economic reforms in China in the late 1970s, economic energy intensity (energy use per unit of economic output) has dropped significantly and energy consumption has grown at slightly over half the rate of economic output. Trends in energy intensity in the industrial sector, by far the most important in the Chinese economy in terms of output and energy consumption, largely determine overall intensity changes. Using multiple data sets for the 1980s, the China Project estimated the relative contributions of subsectoral shifts (relative and subsectoral shares of output) and changes in subsectoral energy intensity (in physical energy intensity of individual products, in product mix within subsectors, fuel switching, and other factors) to the total intensity change (measured in total end-use energy consumption per unit of gross output value). We were not able to assess the roles of some potentially important contributors, e.g., accounting biases, the degree of vertical integration in industries, or hidden inflation in gross output value statistics. Their impact on the relative contributions of structural shifts and intra-subsectoral intensity changes are not clear.

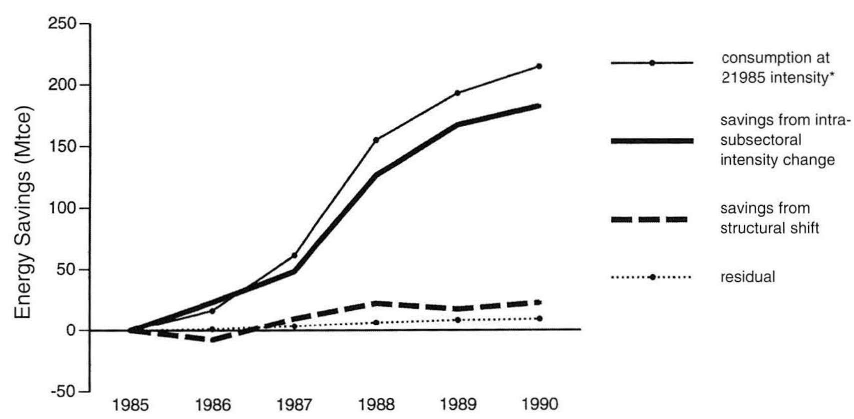
Our results suggest that in the 1980s, while structural shifts were significant, factors represented by subsectoral intensity played the largest role (see Figure for an example of results from one data set). We estimate the actual shares of intra-subsectoral and structural components of industrial sector intensity change for 1980s to be near 70% and 30% of overall intensity change, respectively, plus or minus 10 percentage points in either direction. This estimate counts change in product mix within subsectors as structural change. The magnitudes cannot be determined with precision from the data and methodologies used, but the weight of convergent results from differing data sets and approaches argues in favor of this conclusion.

Much significant structural change occurred in the 1980s, but its net contribution to reducing macroeconomic energy intensity was relatively small. Moreover, shifts toward light industry appeared to be minimally influential in reducing energy intensity. Rather, shifts between relatively energy-intensive subsectors resulted in most of the net savings from structural change. Given this, potential intensity reductions from structural change could be significant in the future.

In the 1980s, the chemicals, machinery, metals, and building materials subsectors accounted for about three-quarters of total energy savings from intra-subsectoral intensity declines. This is not surprising since these sectors consume the bulk of industrial sector energy, and potential savings are correspondingly great. We also found that, at least in 1989-1990, shifts in product mix may have been the major source of intensity change in the chemicals and machinery subsectors. In general, finer disaggregation of Chinese industry data increases the share of overall change due to structural change. We took this into consideration in arriving at the decomposition estimate.

Our results contrast strongly with the prevailing view. The accepted view within China and among many analysts outside China is based on analysis of the Sixth Five-Year Plan period (1981-1985) by the Energy Research Institute. The Institute reports that structural change (including changes in product mix) accounted for one-half of the energy savings in the economy as a whole, imports of energy-intensive products for one-sixth, and improvements in energy management together with technological change, one-third.

The significance of this disagreement lies in China's potential role as a model to other developing countries. If most of the intensity decline was rooted in technical change, and if that change was facilitated by energy-conservation programs, China would be an outstanding example of the potential for government to fundamentally change energy-use patterns to achieve industrial development goals. If most of the intensity decline came from structural change, however, that would argue for the pursuit of energy efficiency



*gross output value in target year multiplied by 1985 gross output value energy intensity

Figure. *Industrial sector energy savings compared to base year (1985), Mtce.*

through macroeconomic policies.

Our work does not address the role of all the factors that result in observed intra-subsectoral intensity change. Further work, e.g., case studies of subsectors that underwent significant intensity changes and of individual enterprises within those subsectors, would be useful in examining the roles of those factors. Some work in this direction was performed for the Sixth Five-Year Plan period, but it still requires clarification and updating. Case studies, carried out over the next year, will contribute not only to understanding how energy intensity has changed, but also to what motivated those changes.

Our analysis is consistent with the view that the government-sponsored program of energy-conservation investments, begun in 1980, had a major role in the intensity decline in the following decade. Cumulative energy savings in 1985 (compared to those in 1980) were about 179 Mtce. Had the conservation-investment program (with estimated 28 Mtce/year of savings capacity) been operational in 1985, it would have accounted for 16% of total energy savings. Conservation investments in the Seventh Five-Year Plan produced estimated energy savings capacity of 24 Mtce/year, about 11% of the 1990 energy savings over 1985 intensity of 210 Mtce. Revised evaluations of the energy-conservation investment programs in the Sixth and Seventh Five-Year Plans are in preparation.

Modeling China's Energy Demand, Supply, and CO_2 Emissions Futures: An Overview

F. Yang, M.D. Levine

China's rapid economic expansion requires huge increases in energy use and produces a corresponding rise in CO_2 emissions levels. These levels are a matter of great concern both for China, already the third-largest emitter of anthropogenic CO_2, and for the world as a whole. To begin to address the problem of emissions, China has developed a number of energy-demand and greenhouse gas emission-forecasting models to improve decisionmakers' ability to evaluate mitigation options. These models were developed through a strong collaboration among designers, energy experts, and decisionmakers.

The China Project has reviewed and evaluated several of the Chinese models in terms of their advantages and limitations, assumptions, and results. The models provide forecasts of energy demand and supply, energy-conservation potential, and greenhouse gas emissions. In the course of our review, we found that:

- most of the forecasts treat energy problems at the national level (as opposed to regional),
- they generally produce short-, medium-, and long-term forecasts (to the year 2050),
- forecasting approaches include optimization programming, input-output tables, energy indices, expert systems, and cybernetic systems, and
- they generally utilize sectoral analysis and scenarios, partly because these forecasts are funded by central government agencies which prefer sectoral results.

Table 1 lists a range of the forecast results from a variety of models.

Most energy-demand forecasts show that economic growth rates, population size, economic structure, and energy-conservation rates (intensity changes) significantly affect energy demand. Adjustments in economic structure and aggressive energy conservation are held to be cost-effective ways to reduce energy demand. Technological progress will have a long-term effect on energy conservation. However, rapid population and industrial growth in rural areas—where 70% of Chinese still live—introduces great uncertainty in the forecasting of long-term demand.

Government agencies have performed energy-supply forecasts up to the year 2000. The official projection for total primary energy supply in that year is 1.4 Gtce, including: 1.4 Gt of raw coal (980 Mtce); 200 Mt crude petroleum (280 Mtce); 20 billion m^3 of natural gas (27 Mtce); 80 GW of hydropower capacity generating 250 TWh/yr (88 Mtce); 5 GW of nuclear power generating 25 TWh/yr (8 Mtce); and 17 Mtce of other energy. Installed generating capacity would reach 240 GW in 2000, half of which would be built in the 1990s.

In addition to the central government, many academic researchers have also

Table 1. *Domestic energy demand in the long-term forecast (Mtce).*

Energy Type	2000	2020	2050
Coal	1000-1100	1700-1800	2445-2956
Oil	200-250	400-500	700-1000
Natural gas	40-50	130-160	210-250
Hydroelectric	90-100	180-220	300-320
Renewable energy*	0	5-10	100-130
Nuclear power	10-14	80-100	300-450
Total commercial energy	1440-1550	2500-2800	4000-4400
Biomass	300-350	200-250	50-100
Total energy demand	1750-1900	2700-3050	4050-4500

*not including biomass

Table 2 . *Domestic energy supply in the long-term forecast (Mtce).*

Energy Type	2000	2020	2050
Coal	1000	1500-1640	2285-2640
Oil	257-286	357-414	242-328
Natural gas	27-33	106-133	173-306
Hydroelectric	56-112	210-238	336-350
Renewable energy*	0	8-10	80-100
Nuclear power	6-8	42-56	280-336
Total commercial energy	1340-1440	2220-2490	3400-4060
Biomass	280-320	150-180	50-100
Total energy demand	1620-1760	2370-2670	3450-4160

*not including biomass

forecast energy supply (Table 2). Most agree that hydropower resources will be completely developed by 2050. Coal will continue to dominate the energy supply, petroleum resources will be quickly depleted in the next two decades, necessitating imports, and natural gas development will rise, but still lag far behind demand. Environmental protection, specifically that of reducing the impacts of coal combustion, will be a crucial factor in accelerating nuclear development. According to government plans, nuclear power will play a major role in overall development of the electricity supply. Renewable energy development will be relatively neglected.

Some analysts have used energy-demand models to forecast CO_2 emissions. They predict emissions to be 0.81-0.85 gigatons of carbon (Gt-C) in 2000, 1.2-1.5 Gt-C in 2020 and 2.2-2.6 in 2050. These analysts argue that structural change in the economy and changes in end-use technology are likely to have a greater impact on CO_2 emissions than fuel-switching. They also feel that the evaluation of alternative energy supply-and-use technologies should take into account both energy conservation and environmental improvement effects.

Future work involves completing the evaluation of Chinese forecasting models and comparing them with the results of efforts in other countries to forecast China's energy demand and greenhouse gas emissions.

Forecasting Energy Use in the Chinese Iron and Steel Industry

X. Xi, M.D. Levine

As part of an effort to analyze past trends and to forecast energy use in major energy-consuming sectors and industries, the China Project developed a base-case projection of the steel industry's growth and energy consumption to the year 2020. The Figure outlines the forecasting procedure.

Along with Russia, Japan, and the United States, China is one of the world's major iron and steel producers. Crude steel output has more than doubled in the past decade, reaching 81 Mt in 1992. Energy use for iron and steel production currently exceeds 90 Mtce, more than 8% of the nation's commercial energy consumption. A continuation of the rapid economic growth of recent years will stimulate more demand for steel, with the corresponding energy use, and require China to develop the world's largest steel industry early in next century.

We used the relationship between demand for steel products and per capita GDP (the latter as the indicator of economic development) as the basis for forecasting steel demand. We assumed that Chinese per capita GDP will continue to grow rapidly—though not as much so as in the past decade—at an average annual growth rate of 6% between 1985 and 2020. We further assume that population will increase slowly, at 0.85% per year during the same period. In 2020, per capita GDP should thus reach $10,358 (61% of 1985 per capita GDP in the U.S.) and the population, 1.421 billion.

Total demand for crude steel is the product of per capita crude steel consumption and population. We examined the relationship between per capita crude steel consumption and per capita GDP in 91 countries in 1985. Our forecast assumes that per capita crude steel consumption will gradually increase with continued economic growth, but because of technological progress as China industrializes, it will remain at levels lower than current values in developed countries. We project demand for crude steel to increase from 66 Mt in 1985 to 270 Mt in 2020, a figure almost equal to the combined crude steel output of Japan, the United States, Germany, Italy, France, and the U.K. in 1992. Per capita steel use is projected to rise from the 1985 base year level of 45 kg to 190 kg in 2020, lower than the 1985 values of 250 kg in the U.K. and France, and far below the 448 kg and 553 kg, respectively, in the United States and Japan.

In projecting future energy use in the

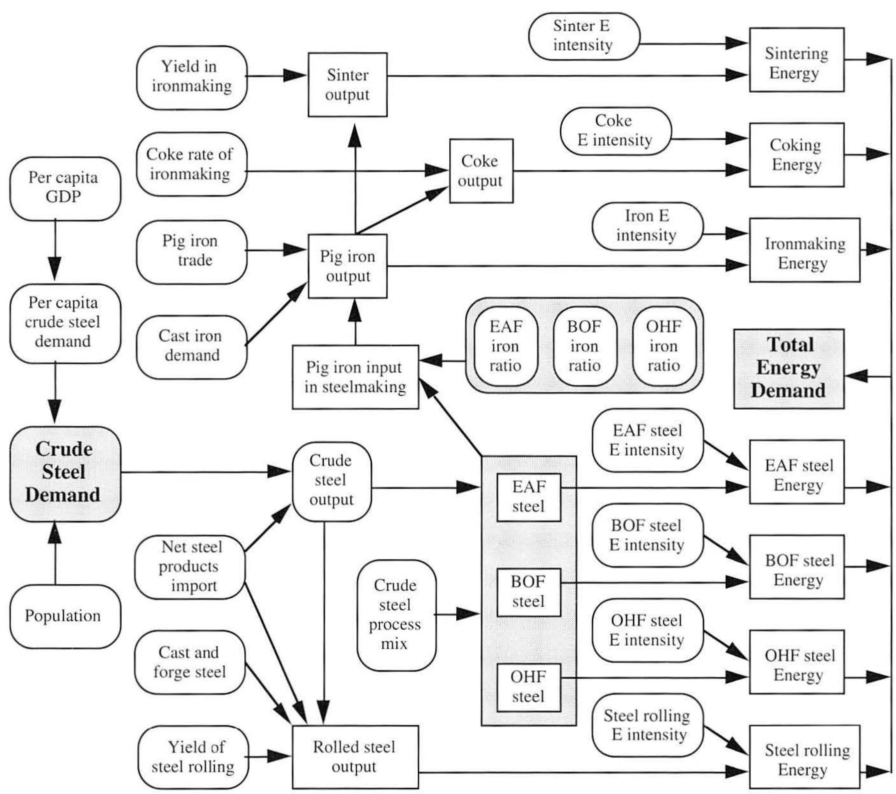


Figure. *Flowchart of the projection of energy use in Chinese iron and steel production. EAF = electric arc furnace; BOF = basic oxygen furnace; OHF = open hearth furnace.*

iron and steel industry, we focused on the currently dominant production route of iron and steel production, which will continue to predominate until 2020. Direct reduction and minimal production are not likely to become significant in the medium term. The production process is divided into five major stages: coking, iron ore preparation, iron making, steel making and steel rolling. We examined current patterns of energy use and energy savings potential in all major stages. Major measures to reduce energy intensities include: 1) increasing the share of continuous casting; 2) replacing existing open hearth furnaces with basic oxygen furnaces and electric arc furnaces; 3) adopting appropriate technologies to recover waste energy; 4) developing advanced continuous casting technologies; 5) using advanced moni-toring and control technologies; 6) improving production practices to reduce heat loss between processes; and 7) using energy-efficient electric drive systems. We assumed that the energy intensity of each stage will reach the 1983 U.S. industry values in 2000 and current state-of-the-art values in 2020.

Taking into account these assumptions, as well as projected changes in the mix of steel-making processes, imports and exports of iron and steel products, and input-output ratios at all stages of production, we projected total energy use in iron and steel production to increase from 56 Mtce in 1985 to 163 Mtce in 2020. At the same time, we project energy intensity to decrease by almost half from 1200 kgce/ton of crude steel to 634 kgce/ton of crude steel, lower than intensity in both the United States and Japan in the mid-1980s.

A Review of China's Energy Policy

F. Yang, N. Martin, M.D. Levine

China's tremendous rate of economic expansion has been hailed as an excellent example of the ability to stimulate economic growth. However, China's reliance on fossil fuels—especially coal—may hasten the degradation of the environmental quality. Therefore, understanding the structure and context of energy policy decisionmaking and the direction of energy policy can help gauge the Chinese government's future policies.

This research focuses on an assessment of China's energy institutions and energy policies during the period of central planning (1945-1979) and the more current period of transition to a market economy (1979-1993). We identify factors affecting the future of China's energy sector and energy institutions. The work has benefited from substantial input from Chinese energy policy analysts who contributed primary source material.

Our research indicates that rapid institutional changes during the central planning period coupled with an inflexible institutional framework hampered the full development of energy resources. The central planning mechanisms (fixed prices, full employment, quota systems, etc.), while effective during the early years of development, were a drain on the energy sector by the mid-1970s.

The transition period has been characterized by the rapid transition to market mechanisms, including attempts to rationalize energy prices, lower labor costs, increase private investment, and give more independence to energy corporations and state-owned enterprises. Policies, however, continue to be developed and implemented with extreme caution, and only the power subsector has made significant advances toward a market structure and operation. Given the fact that current energy-demand forecasting predicts a doubling of current primary energy consumption by 2020, the need to implement market and institutional reforms rapidly to reduce inefficient energy utilization becomes even more important.

International Energy Studies

Mind the Gap! Test and Real-World Fuel Economy in New Cars

L.J. Schipper, W. Tax

Since the early 1970s, the efforts to improve new car fuel economy in the United States and many other countries have brought about surprising results. While the sales-weighted test figures for new cars have dropped markedly in almost all countries (Fig. 1), the on-the-road figures for actual fleets have shown much smaller changes in Europe (Fig. 2). This difference is due in large part to the fuel economy "gap" between the test and actual fuel con-sumption of new cars. This gap has grown in many countries, which causes concern among transportation, energy, and environmental authorities.

We have reviewed analyses of this gap in Canada and five Western European countries. Our results were not surprising: new car fuel economy as defined by tests is 20-25% better than that achieved in the real world. Part of the problem is that tests do not match well with actual driving patterns. Another problem is that the behavior of individual drivers (including the influence of cold starts) is worse than what the tests reflect. Ironically, the Swedish tests and actual results (as compiled by driver surveys) agree to within 3%, because the procedure for weighting driving cycles overemphasizes the city (i.e., fuel-intensive) part of the overall cycle. This suggests that some of the gap can be reduced by carefully manipulating figures from a variety of tests. But the real problem is only solved if authorities conduct careful surveys of actual driving (as has been done in France, Canada, the United States, and Sweden) to determine the relative importance of the various factors that degrade fuel economy from its test value. Future fuel-saving strategies may well focus on these behavioral factors rather than only on stimulating nominal improvements in fuel economy that are not realized in practice.

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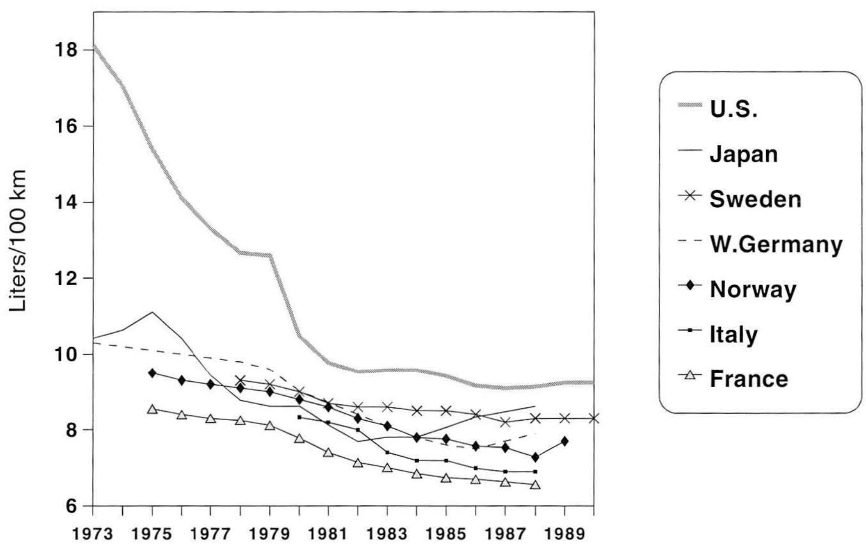

Fig. 1. *New car fuel economy (sales-weighted test values).*

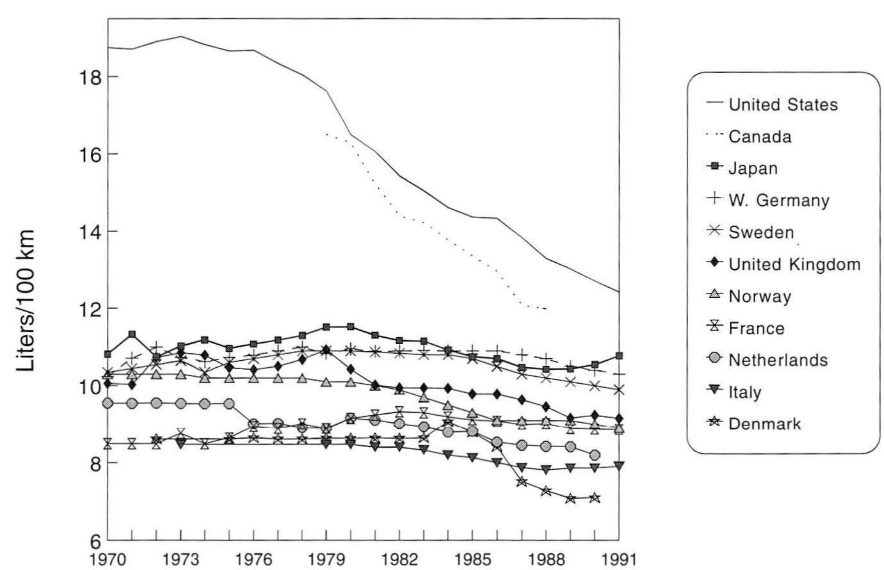

Fig. 2. *Actual, on-road automobile fuel economy (fleet averages).*

Taxation on Automobiles, Driving, and Fuel in OECD Countries: Truth and Consequences

L.J. Schipper, G. Eriksson, O. Johansson†, W. Tax*

There is a consensus that a multitude of challenges confronts ever-increasing motorization, mobility, traffic, energy use, and pollution from road vehicles, particularly in the cities of OECD countries and major developing countries. Motivated both by fiscal concerns and, more recently, by environment and energy interests as well, most developed countries have used market instruments to restrain fuel and automobile use. Not surprisingly, the Japanese and Western Europeans use 65-75% less fuel per capita than do Americans.

Using cross-sectional comparisons, we estimate that in Europe, high automobile fuel taxes and taxation of vehicles together have contributed to much of this gap in fuel use. Our calculation yields a long-run elasticity of fuel use with respect to fuel price of approximately -0.8, of which -0.5 is from changes in the fuel intensity of the stock of vehicles, -0.25 is from the change in distance driven, and -0.05 is from a change in ownership of cars. Since fuel taxes make up most of the differences in the price of fuel between countries, this illustrates the importance of fuel taxation in determining fuel use. When we examined differences in how new cars were taxed, we found that these affect fuel use as well. But a dollar of tax levied on fuel causes a far greater reduction in fuel use than a dollar levied on the value, weight, and/or engine displacement of a car.

The Figure shows how the total burden of acquisition and yearly cars taxes, as well as taxes on gasoline, accounted over a 10-year car lifetime and discounted at 5%. The values refer to the average mixof cars sold in the United States, but under the regimes of each country.

Differences in fuel prices are only part of the story. Very high purchase taxes and other fiscal schemes have been particularly effective in restraining car size in Denmark, Norway, and Italy, and restrained ownership as well in Denmark. Taxes on weight, horsepower, or displacement have a smaller effect, although some cars are designed with these parameters just below thresholds for higher taxation. In general, these taxes were motivated by revenue concerns, not for purposes of saving energy or restraining emissions. However, some countries have implemented CO_2 and other environmental taxes on fuels.

Company car taxation policies in the UK, Sweden, and West Germany have had the opposite effect on both ownership and size, offsetting the effects of other fiscal policies for 20%-60% of those drivers who receive new cars from their employers. The average weight and horsepower of new company cars is significantly greater than those of the new car population as a whole.

Our study indicates that taxation schemes designed to affect automobile ownership, characteristics, or use must be blunt, i.e., effectively increase the cost of moving a kilometer or buying a less efficient car if such policies are to be effective. Our preliminary results show that these taxes should be aimed directly at fuel prices or the test fuel economy of cars.

In future work, we will expand and complete our economic analysis of car ownership, fuel economy, and use. We will extend the modeling to estimate the effects of the various tax schemes in use in the countries we are studying.

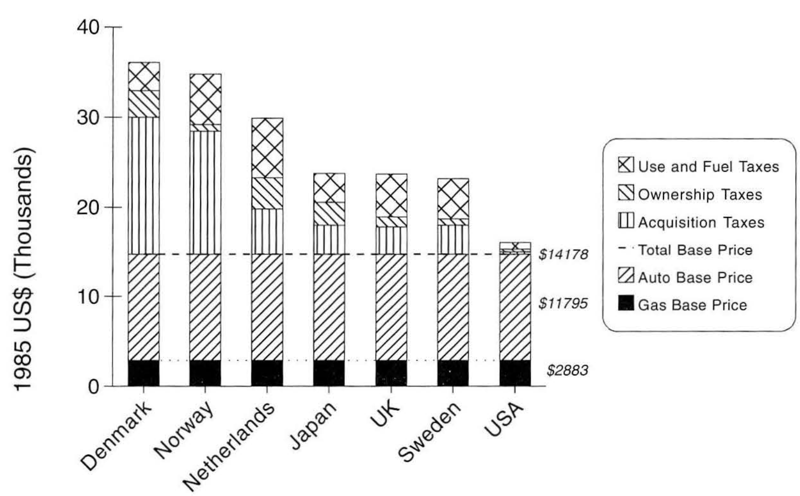

Figure. *Automobile taxation according to 1990 tax schemes.*

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Energy Use and Efficiency in Sweden: A Retrospective Analysis

L.J. Schipper, L. Price

A detailed analysis of the differences in the structure of energy use in Sweden and the U.S. in the 1970-1972 period found that energy use in Sweden at that time was more efficient than in the U.S. and in many other OECD countries. Since then, major changes have taken place in the economies of both countries. Has Sweden remained the energy efficiency leader? Our somewhat surprising answer is "probably not." We found that while the Swedes still have the most efficiently heated residential buildings, efficiency improvements in that sector since the early 1970s have been small relative to the large gains that occurred in other European countries and the U.S. Similarly, energy intensity in Swedish manufacturing fell at about the average pace for Europe, but slightly less than in the U.S. or Japan. The energy intensity of Swedish passenger transportation barely declined, which was typical for Europe, while the intensity of freight increased in Sweden as well as in most other countries.

The Figure (next page) summarizes the achievements in Sweden by holding the structure of energy use in each sector constant and relating the resulting changes in energy intensities to their 1973 levels. While Sweden's reductions ranked fifth, Sweden's economy is one of the most energy-intensive structures in Europe. As a result, a significant potential for improved efficiency remains. Future energy prices and energy efficiency programs will determine how much of that large potential is actually realized.

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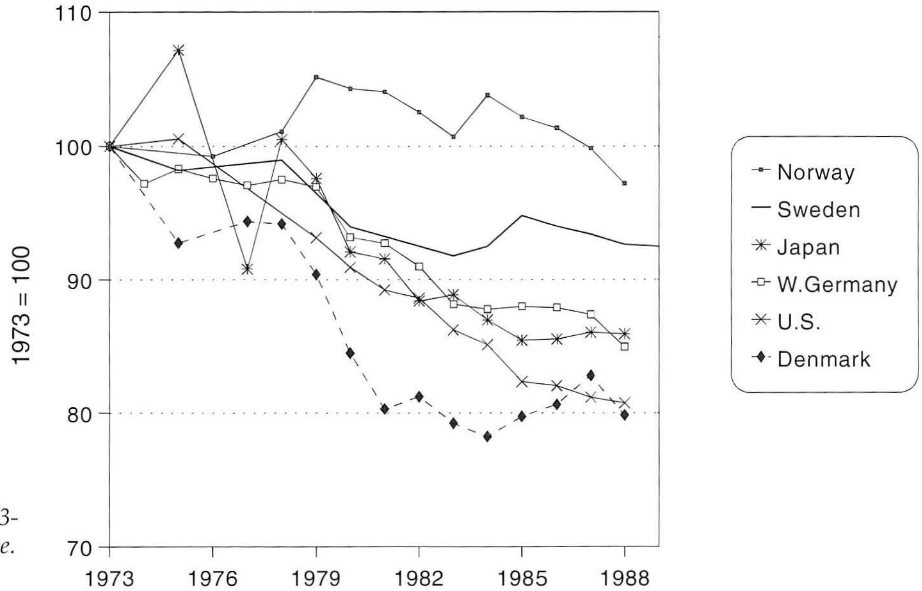

Figure. *Primary energy intensities 1973-1989, all sectors, constant 1973 structure.*

A Sectoral Analysis of Carbon Emissions from Energy Use in Sweden, 1970-1990

P. Monahan, L.J. Schipper

Interest in analysis of CO_2 emissions from fossil fuel use has grown because of concern over the greenhouse effect. While many efforts to trace emissions to various fuels have been made, efforts to trace them to a disaggregated pattern of energy use by end use, or the economic subsector where emissions arise, have been few. We have undertaken such an analysis for Sweden.

Our most surprising finding is that the evolution of carbon emissions in Sweden may be atypical for industrialized countries. While changes in carbon emissions are closely linked with changes in primary energy use in most countries, the Swedish case illustrates how a low-carbon fuel mix can lead to a decoupling of energy use from carbon emissions. Primary energy use in Sweden grew more than 20% between 1970 and 1990, while the amount of carbon dioxide emissions from energy consumption shrank by 40%. Sweden's fuel shift in the electric power sector away from carbon-emitting fuels to hydropower and nuclear power is the primary reason for this trend. While final energy use remained fairly constant, electricity use increased as a share of final energy use from 15% in 1970 to 33% in 1990. This change in itself resulted in lower fossil fuel use (primarily oil) for space heating. On a per capita basis, carbon emissions fell from 3.5 to 1.9 tons carbon/person. On a value-added, or carbon-intensity, basis, emissions shrank from 0.46 to 0.18 MtC/billion US$.

The Figure shows the relative contribution of each sector to total emissions, separated to emphasize each sector's contribution. The drop in emissions in both manufacturing and households, which dominated the total in the early 1970s, stands in contrast to the slow rise in travel (essentially tied with the manufacturing sector) and freight. This contrast is found in many countries, but the sharpness of the decline in emissions in Sweden for manufacturing, households, and services is unusual for an industrialized country.

The components of changes in emissions are several. Substitution of electricity (based on hydropower and nuclear power) and district heat (based increas-

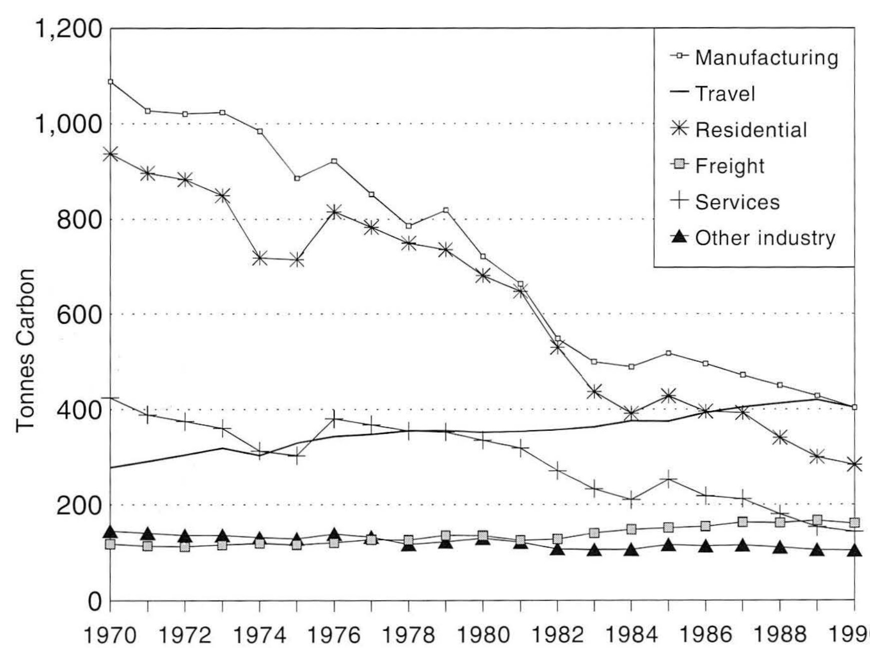

Figure. *Per capita carbon emissions by sector.*

ingly on renewables), as well as direct use of wood in place of oil in homes and industry, permitted the greatest decline in the ratio of emissions to unit activity (manufacturing output, space heated, and so forth). Improved energy efficiencies provided the second most important element of reduction, at least in homes, buildings, and industry. Shifts among the mix of goods produced in Sweden actually led to a slight increase in energy use, but much of this shift arose because of increases in paper and pulp production, which in turn was based largely on the use of electricity and wood-based fuels. Shifts in consumer activities and lifestyles (larger homes, more travel) all increased CO_2 emissions, although not as much as the increase in the GDP.

Thus we see that all the important changes in the structure of energy use in Sweden led to restraint or reduction in CO_2 emissions. Fuel switching and improved efficiency caused an absolute decline in emissions, while the overall effect of changes in the mix of goods produced and consumed caused a small increase in emissions that was still less than the overall rise in GDP.

Can other countries repeat Sweden's achievement? That is difficult to say, since CO_2 emissions reduction per se was not the goal of any particular policy. Small carbon taxes were only introduced around 1990. But other countries with more carbon-intensive economies would do well to study these results in Sweden to see which ingredients are appealing and at what cost.

Residential Sector Carbon Dioxide Emissions in OECD Countries, 1973-1990: A Comparative Analysis

C. Sheinbaum, L.J. Schipper

Concern over the impact of anthropogenic $C0_2$ emissions on the climate and the biosphere has caused researchers to focus attention on their principal source, fossil fuel use. To gain a better understanding of how emissions are linked to the activities for which energy is used, the LBL International Energy Studies Group undertook a detailed study of the residential sector in countries of the Organization for Economic Cooperation and Development (OECD).

The evolution of carbon emissions from energy use in the residential sector for nine OECD countries for 1973-1990 was analyzed. Results are presented both at an aggregate level and by end use (Figure), using carbon emission coefficients for primary energy use. Following the methodology of previous studies, we also review how changes in activity, structure, and intensity had affected both primary energy use and the resulting carbon dioxide emissions on each country.

We find that the level of household energy services (home size, numbers of appliances, and so on), energy efficiency, fuel mix, and power-generation fuels all play an important role in determining the level of per capita CO_2 emissions. In every country, growth in energy services increased emissions while energy efficiency improvements reduced emissions. Fuel substitution had a complicated effect. Although the use of coal declined in every country studied, the increased use of electricity (from increases in appliance ownership and, in some cases, substitution of electricity for fuel for cooking, water heating, and space heating) raised overall emissions where coal or oil were the dominant sources of generation, but lowered emissions significantly where hydro or nuclear power were the most important sources for electric power (France, Norway, and Sweden). The U.K. presented an intermediate case, since power generation has been based on coal, but electricity lost market shares to gas in many end uses.

We note that space heating is the most important source of CO_2 emissions, but that increased electricity use for appliances and lighting is also important. To control emissions, improved end-use efficiency, improved efficiency in power generation, and substitutions for carbon-intensive fuels can play substantial roles.

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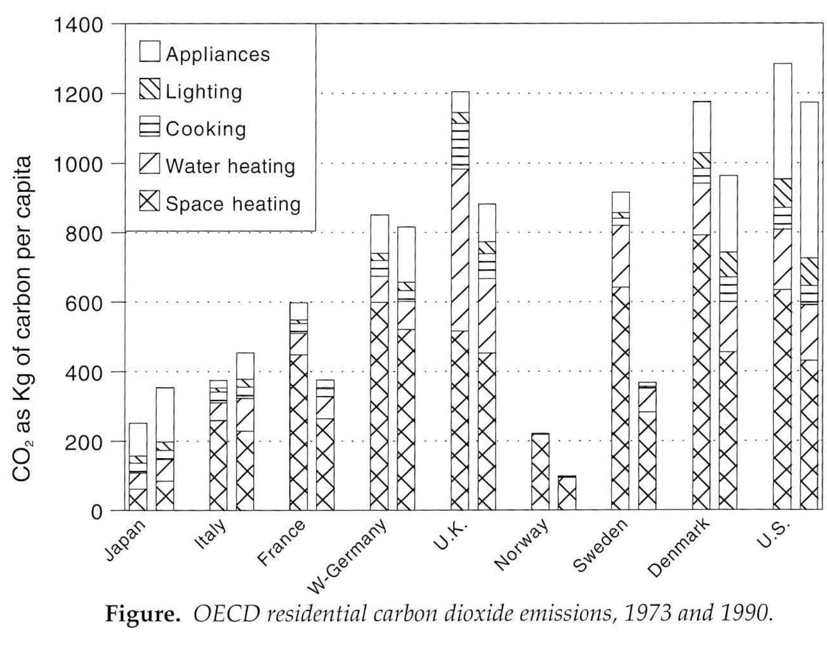

Figure. *OECD residential carbon dioxide emissions, 1973 and 1990.*

OECD Household Energy Efficiency Use after the Oil Price Crash: End of an Era?

L.J. Schipper, C. Sheinbaum, S. Prudham

We have analyzed developments in the structure and efficiency of household energy use in the Organization for Economic Cooperation and Development (OECD) countries through 1990. Focusing on the period since the oil price crash of 1986, we find a clear slowdown in the rate of improvement of space-heating efficiency. By contrast, the efficiency of electric appliances appears to be increasing steadily and may accelerate as utility and government programs reinforce the market pressures for greater efficiency that built up during the 1980s. Household energy intensities declined overall 2.5%/year between 1973 and 1985 but only 1.2%/year between 1985 and 1990 (Figure). Higher energy prices were the most important stimulus, but efficiency programs, particularly thermal standards on new homes and some appliance efficiency programs, played a role as well.

Efficiency improvements were not the only changes that occurred, however. Larger homes, increased appliance ownership, and smaller households combined to boost energy use significantly throughout the entire period. These income-driven increases offset gains from efficiency in many, but not all, countries. Nonetheless, energy services are beginning to saturate in all countries studied except Italy, Japan, and Great Britain. This means that future increases in incomes will not result in the same percentage increases in household energy use as in the past.

Currently, concerns over the environment and the greenhouse effect have focused attention on the evolution of energy use in each major sector. Future household energy use depends on the competition between structural factors that increase energy use and technical and behavioral forces that could either reduce or increase future energy intensities. With present trends, total household energy use will begin to increase in most OECD countries unless a combination of higher energy prices (which stimulate energy-saving behavior as well as accelerated takeup of energy-efficient technologies) and efficiency programs rekindle interest in improving efficiency.

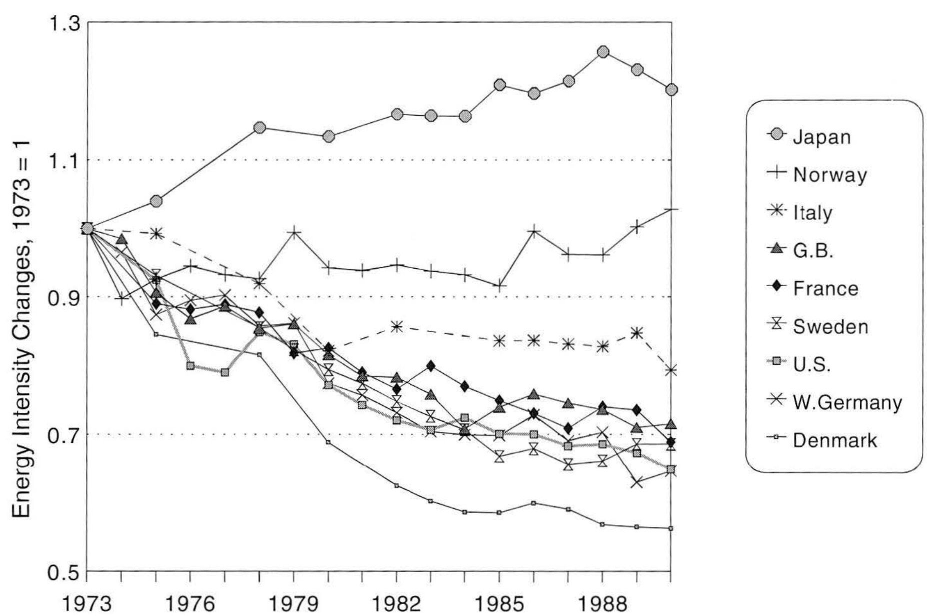

Figure. *The impact of intensity changes on delivered residential energy use.*

Comparing Energy Efficiency in Japan and the United States: A Long-Term Perspective

L.J. Schipper, W.H. Golove, H. Nishimaki†*

The success of Japan in the international business arena has led to a close scrutiny of U.S. business practices, especially vis-à-vis their Japanese competition. One statistic that stands out as a possible source of competitive advantage is the apparent efficiency with which the Japanese economy utilizes energy.

In 1988, the energy/GDP ratio, a measure of total energy consumption across the economy divided by the total GDP, was 12.62 MJ per 1980 U.S. dollar for Japan. This same ratio was over 60% higher for the United States at 20.39 MJ per 1980 U.S. dollar.

To understand the nature of this difference, we compared energy-consumption patterns in Japan with energy use in the United States for 25 economic sectors from 1970 to 1988 using a structure and intensity (STRINT) analysis.

STRINT is a method of disaggregating factors contributing to energy consumption which allows us to distinguish among changes in the level of economic activity in the various sectors, changes in output within a given sector, and the efficiency with which a specific process is achieved. We used data collected primarily by the U.S. Energy Information Administration as well as a variety of detailed Japanese-language sources.

Our conclusions confirm the perception that Japanese industries use significantly less energy than their American counterparts to produce similar products. We also found that major appliances in Japan consume slightly less energy for a given level of service than the appliances in American homes. Japanese trucking uses less energy per tonne-km than American trucking, a consequence of the relatively low level of long-haul trucking in Japan. We also found that the Japanese use far less heat per square meter and degree-day

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than Americans; the main reason is that they keep indoor temperatures much lower and heat only intermittently.

Indeed, less than half of the difference in the energy/GDP ratio was caused by greater efficiency in Japan; the major factor is lifestyle, specifically housing size and automobile travel. The average Japanese home, for example, is less than 85 m^2, whereas the average U.S. home is larger than 140 m^2. Likewise, the average Japanese travels less than 10,000 kilometers in automobiles per year, while an average American travels more than 22,000.

Details of the comparisons of the specific sectors have been published in prior papers. The important contribution of this effort is to extend the period of evaluation. For example, we found that while energy savings in the U.S. between 1973 and 1990 were spread over all sectors, these improvements in Japan were focused mainly in the industrial sector. In the coming year, the dataset developed for this analysis will be expanded for use in a long-term comparison, examining energy consumption from 1960 to the present for both nations.

This extended period is important because it will provide a look at energy-consumption patterns in a period of relatively stable prices, similar to the current period. Understanding consumption patterns in such a price regime will provide important information for policymakers today. Limitations on the availability of data, especially for the years prior to 1970, may affect the level of detailed analysis, but we expect to gain important insights nonetheless.

Energy Use and Efficiency in a Small, Formerly Planned Economy: The Case of Estonia

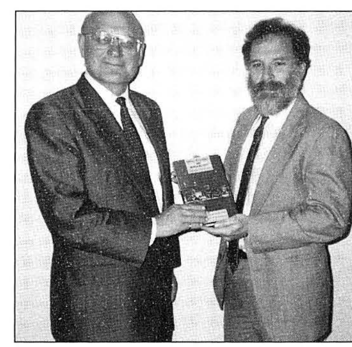
L.J. Schipper, E. Martinot, P. McCoy, M. Khrushch, J. Salay, C. Sheinbaum, D. Vorsatz

Until the collapse of the Soviet Union, Estonia enjoyed the "highest" material standard of living in the region without much of the heavy industrial activity that characterized other Republics or countries in Eastern Europe. In spite of this, however, per capita energy use for industry was high, as was energy use for space heating relative to total space heated. In an economy with low energy prices, few private incentives for efficiency, and little technology for controlling energy use, the high energy intensity of Estonia's economy was not surprising.

By adjusting official energy statistics to make them comparable to those of Western countries, we compared Estonia's per capita energy use with that of several Western countries (Figure). Differences in energy use depend on both differences in the activity for which energy is used (such as production, distance traveled, total area heated), and differences in energy intensity, or energy use per unit of activity. Estonians had less living space, traveled less (and had far fewer cars) than people in the other countries. Estonia produced less heavy industrial output than Denmark, Germany, or the United States. Taken alone, these factors should have reduced Estonia's per capita energy use. But energy intensities in Estonia vary from slightly to significantly higher than those in Western Europe. This tends to raise per capita energy use. Hence, per capita energy use in Estonia was roughly equivalent to that in Western Europe in 1988.

Inefficiencies made up for the lower living standards or output. The drop in industrial energy use was caused by economic collapse; in all likelihood, efficiency of energy uses actually dropped because the utilization of industrial equipment fell. Huge nominal increases in energy prices were matched by inflation or by the accumulation of large debts owed the energy authorities by many classes of users.

In our current work, we are analyzing how energy use in buildings, industry, and transportation can be improved with economic reform, modernization, and with the application of energy efficiency strategies. Industry must be rebuilt; transportation energy use, swelled by the infusion of imported Western-made cars and now light trucks, may be moderated as fuel prices rise. Housing is particularly vexing; the privatization of ownership (or at least reorganization) is proceeding very slowly, as is the effort to begin to install meters and controls on individual buildings or flats. Unsubsidized heat costs in homes connected to district heating may be larger then rents, leading to considerable disaffection and even individuals disconnecting from the public heat supply and switching to electricity. Our longer-term goal in the present work is to help housing authorities incorporate efficiency concerns in the reformulation of housing policies and institutions.



Shown with the Estonian Minister of Energy, researcher Lee Schipper (right) displays his recent book, Energy Efficiency and Human Activity.

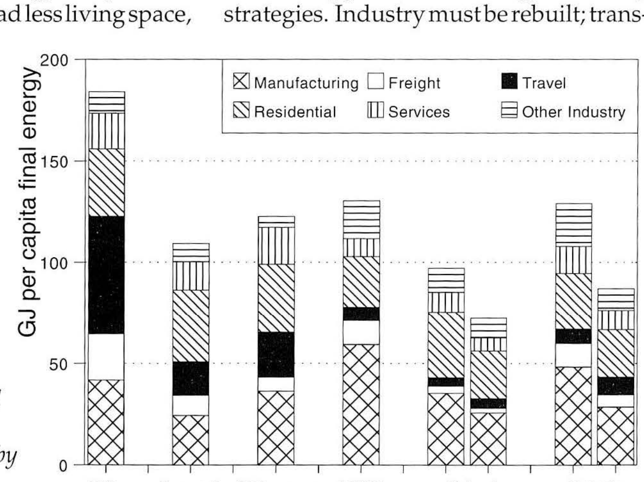


Figure. *International comparison of final energy use per capita by end-use sector.*

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Electricity Efficiency and Future Electricity Demand in Former Soviet Republics: Constraints and Opportunities

L.J. Schipper, E. Martinot

During the past three years, we have analyzed electricity use in the former Soviet Union. We found that over the next 20 years electricity efficiency could be doubled. This improvement could reduce fuel use to below 1990 levels and limit growth in electricity use to well under half the rate of increase in economic activity.

While Russia and some of the other former Soviet Republics enjoy ample energy resources, the accident at Chernobyl in 1986 and subsequent problems with other Soviet-style reactors in Russia and other countries raised concerns among nuclear safety experts over the future of these reactors. Consequently, the G-7 governments* asked the World Bank and the International Energy Agency to examine alternatives to the continued use of these reactors in their present condition. Suggested alternatives included such measures as safety upgrading, the substitution of other electricity supplies, and more efficient electricity use.

Our role in this study was to assist these international authorities in building a model of final energy demand in Russia, Ukraine, and Lithuania, and to estimate the near- and long-term potential for electricity savings. Figure 1 shows the patterns of use in 1990. In the near term, the collapse of the economies of these countries "saved" electricity, but authorities chose not to cash in on these savings by reducing the use of nuclear power. In the longer term, however, a combination of market forces, i.e., competitive forces between firms in these countries and elsewhere, enhanced trade or local manufacture of electricity-using systems (motors, lights, appliances), and a variety of energy efficiency programs, could accelerate the expected improvements in efficiency of electricity use.

Figure 2 shows the potential for reducing the use of electricity relative to activity or output, or electricity intensity, based on three scenarios reflecting conditions in the year 2010. In "Slow Reform" the present indeterminism rules the economies of these countries. Of course, economic growth is very slow, so growth of electricity demand is also slow. In "Rapid Reform" more rapid transition to a market economy takes place, as has been occurring in Poland. Since more equipment is replaced with energy- and electricity-efficient equipment from other countries, the use of electricity is restrained even further, and intensities catch up to those typical in the West in 1990. Finally, in "Extra Effort" a variety of projects that induce foreign firms to invest in local facilities to produce very electricity-efficient equipment pushes intensities down even further, so that they approach those of the West by the year 2010.

Market forces, both affecting the pricing of energy and fuels and the metering of individual users, are essential for making these improvements, but acting alone, market forces might take decades to forge the improvements that could restrain or lower reliance on the unsafe reactors. In our study, we suggested a limited number of policy initiatives that could accelerate efficiency improvements, focusingprimarily on industrial electricity use in the near term and on industries and markets for new equipment for homes and buildings in the medium and longer term. But we argue that these

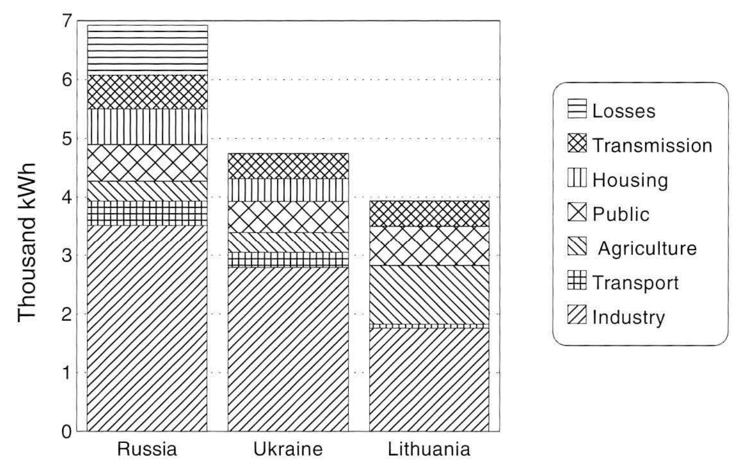

Fig. 1. *Electricity use in former Soviet Republics, per capita values for 1990.*

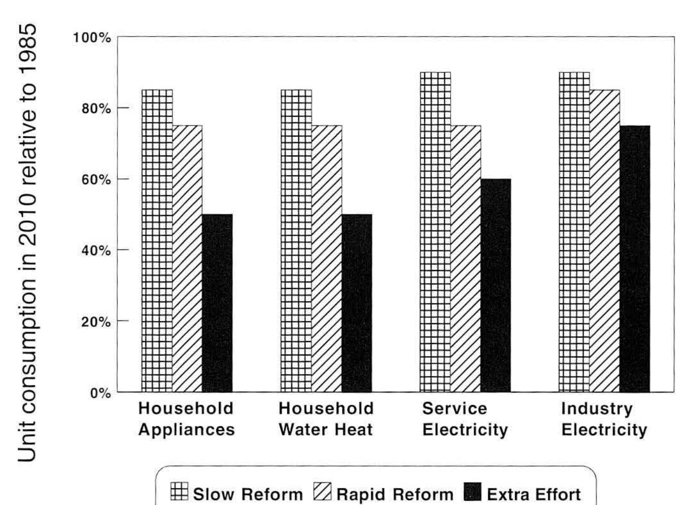

Fig. 2. *Electricity intensities in the former Soviet Republics in 2010, unit consumptions compared to 1985.*

*Canada, France, Germany, Italy, Japan, United States, and United Kingdom.

longer-term strategies are best channeled through the public and private authorities or individuals responsible for housing, commercial and public buildings, and agricultural and industrial redevelopment, as well as the replacement or expansion of vehicle stocks and the road and rail system. Our argument is simple: for most of the activities in these sectors, wide-ranging economic and social reforms are underway, which, however slow and irregular their present pace, have a far greater economic value than just changes in energy use. In other words, improvements in energy efficiency are easiest to undertake if they ride the wave of economic reform, rather than being stimulated for their own sake.

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Energy Use in Poland: Sectoral Analysis and International Comparison

S. Meyers, L.J. Schipper, J. Salay

Along with other former centrally planned economies in Central Europe, Poland has been in the midst of a profound transformation since 1989. As the locus of economic decisionmaking shifts from central planning to the market and changes take place in ownership and in how prices are set, changes in the way energy is used are to be expected. In this project, we collaborated with Polish researchers to conduct an analysis of how and why energy use has changed in Poland since the 1970s, with particular emphasis on changes since 1989.

The economic downturn in 1989-1991 resulted in a significant decrease in energy use in all sectors. Total final energy use in 1991 was 25% below that in 1988 and the lowest since 1974. The most important factors behind the large decline in energy use were a sharp fall in industrial output and a huge drop in residential coal use driven by higher prices. The structural shift away from heavy industry was slight. Key factors that lessened the decrease in energy use after 1989 were the rise in energy intensity in many heavy industries (related to low utilization of capacity) and a shift toward greater use of cars and trucks in passenger and freight transport. Higher energy prices have had an evident impact in the residential sector, but in industry there is relatively little sign of energy conservation through 1991.

We also compared energy use in Poland and the factors that shape it with similar elements in the West. We made a number of modifications to the Polish energy data to bring them closer to a Western energy-accounting framework and augmented these with a variety of estimates in order to construct a sufficiently detailed portrait of Polish energy use to allow comparison with Western data. Per capita energy use in Poland is not much below Western European levels despite Poland's much lower GDP per capita. Poland has comparatively high energy intensities in manu-facturing and residential space heating and a large share of heavy industries in manufacturing output, all factors that contribute to higher energy use per capita. The structure of passenger and freight transportation and the energy intensity of automobiles contribute to lower energy use per capita in Poland than in Western Europe, but the patterns in Poland are moving closer to those that prevail in the West.

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Costs of Reducing Carbon Emissions from the Energy Sector: Brazil, China, and India

J. Sathaye, A.H. Sanstad, P. Monahan, N. Mongia, S. Zhang

This project examines long-term energy and environmental trends in developing countries. In previous phases we built a modeling framework for scenario analysis. We also established a network of analysts from several of the largest energy-consuming developing countries to create country-specific scenarios of long-term energy use and carbon emissions. In the most recent phase of the project, we have performed integrated analyses of how technological change and energy policies may affect energy demands, energy sector costs, and carbon emissions in Brazil, China, and India. For each country, three scenarios were developed and analyzed: "current trends," "efficiency," in which significant improvements in the energy efficiency of technology are projected, and "low-carbon," in which the policy objective is to minimize carbon emissions subject to meeting demands for energy services.

China and India are among the top five emitters of carbon from energy use in the world; China ranks third; India, fifth; and Brazil, nineteenth. Each country aspires to rapid economic growth in the future. Among the three, only China has demonstrated that rapid economic growth can be achieved while maintaining much slower energy and carbon emissions growth.

If current trends in efficiency improvement and fuel mix continue, energy use will increase almost fivefold in Brazil and India and threefold in China. Selected electricity efficiency improvements, supplemented by a 10% transport sector efficiency improvement in Brazil, can reduce the increased use of energy by 10-12% in the future at no net cost to the economy. Tightened restrictions on carbon emissions will reduce primary energy use further in the low-carbon scenario in India and China as oil and gas are substituted for coal, but primary energy use will increase sharply in Brazil where more renewable biomass, which has a lower thermal efficiency, is used.

Because of its large biomass resource, Brazil has the potential to reduce future emissions by 50% in the low-carbon

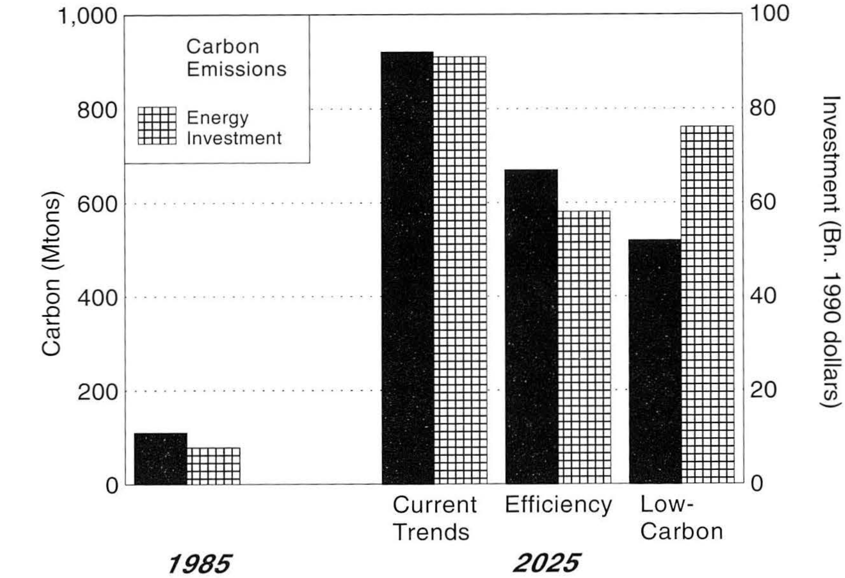

Figure. *Carbon scenarios in India, the effect on energy system investment.*

case compared to the current trends scenario, at no additional cost to the economy. A similar 44% reduction could also be achieved in India by shifting toward more efficient uses of biomass and switching from coal to oil and gas. For China, oil and gas imports could serve as the primary means of reducing emissions, since efficiency improvements are already strong in the current trends scenario.

The incremental cost of reducing carbon emissions will depend on the choice of the baseline. Using current trends as the baseline, costs are positive only for China; that is, reduced levels of future carbon emissions could be achieved in Brazil and India at no net cost (Figure). By contrast, with the efficiency scenario as the baseline, the model yields positive incremental costs for each of the countries.

Capital investment and foreign exchange, two GDP components of critical concern to developing countries, show divergent trends among the three countries. For India, GDP shares of both components increase over time, indicating a clear need for higher savings or increased exports to finance future energy infrastructure requirements. For China, anticipated high economic growth reverses the past investment trend of a rising GDP share. Rapid economic growth will also permit China to lower its future emissions by expanded use of imported gas and oil.

Costs of CO_2 Mitigation Options in Tropical Forests

J. Sathaye, W. Makundi

Carbon dioxide (CO_2) emissions from the burning of tropical forests rival those from energy use in the developing countries. However, recent studies suggest a decline in the deforestation rates and the associated carbon emissions from some developing countries. LBL studies of trends in the late 1980s estimate a positive net annual carbon balance for India and a positive net committed carbon balance for Malaysia. Such changes hold the promise of forestry creating sinks for carbon emissions from other sources. Indeed, continued tree planting has the potential to offset as much as 25% of India's CO_2 emissions from energy by the year 2005.

The efforts to reduce deforestation and to increase the land area under tree cover vary across countries. Thailand and China have set goals of increasing their tree cover to 40% and 17%, respectively, of their land area. In India, although no target has been set, the Forest Conservation Act of 1980 has served to slow continued deforestation.

The forestry options for mitigating carbon emissions consist of reducing deforestation, increasing the carbon pool through forest management, more efficient conversion to forest products, and planting more woody biomass. The set of options varies among countries but many cost-effective options may be identified in each country. Investment costs per ton of carbon for these options vary by orders of magnitude within a country and across nations. These costs are often lower than alternative energy options. Availability of land does not appear to be an immediate constraint—even in heavily populated India.

LBL has worked closely with researchers in nine developing countries to identify and analyze mitigation options. The analysis indicates that the technical potential to sequester carbon ranges from 200 million tons in Thailand, to 3.9 billion in China, to almost 5 billion in India. About 80% of the potential can be tapped at an initial cost of less than $10 per ton of carbon in India and China and less than $20 in Thailand. Initial costs include the investment cost of projects; for projects managed in rotation, it is the discounted value of all future investments. No operating costs are included.

The potential to sequester carbon in forests is very large in each country compared to its CO_2 emissions. The potential is almost 25 times India's and six times China's current energy emissions. Strong development of the forest sector holds the promise to balance a significant share of the energy emissions from these and other countries.

Tapping this potential will require that many barriers to protection and afforestation programs be overcome. In Thailand, the opportunity cost of land (almost 20 times the benefit from tourism, watershed management, and so on, derived from forest protection) is a deterrent to programs to protect forests. In India, the farmer's high discount rate turns a project with a high societal benefit into an unprofitable one. Identifying these barriers and overcoming them is a challenge that will need to be met in order to foster sustainable development and management of forest resources.

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Prospects for the Power Sector in Nine Developing Countries

S. Meyers, N. Goldman, N. Martin, R. Friedmann

On the basis of information drawn primarily from official planning documents issued by national governments and utilities, we examined the outlook for the power sector in the year 2000 in nine countries: China, India, Indonesia, Thailand, the Philippines, South Korea, Taiwan, Argentina, and Mexico. We found that the implicit rates of average annual growth of installed electric power capacity between 1991 and 2001 range from a low of 3.3% per year in Argentina to a high of 13.2% per year in Indonesia. All five of the East Asian countries plan increases in capacity averaging over 7% per year. In absolute terms, China and India account for the vast majority of the growth among the study countries. The plans call for a shift in the generating mix toward coal in six of the countries (Figure) and continued strong reliance on coal in China and India. The use of natural gas (from either domestic supplies or imported LNG) is expected to increase substantially in a number of the countries. The historic movement away from oil continues, although some countries maintain dual-fuel capabilities.

Plans call for considerable growth of nuclear power in South Korea and China and modest increases in India and Taiwan. Hydroelectric capacity is expected to expand in every country, but in most cases the absolute growth is modest, and public opposition and high capital cost could constrain construction of large hydroelectric plants.

The feasibility of the official plans varies among the countries. Lack of public capital is leading toward greater reliance on participation by the private sector in power projects in many of the countries. Environmental issues are becoming a more significant constraint than in the past, particularly in the case of large-scale hydroelectric projects. The financial and environmental constraints are leading to a rising interest in methods of improving the efficiency of electricity supply and end use. The scale of such activities is growing in most of the study countries.

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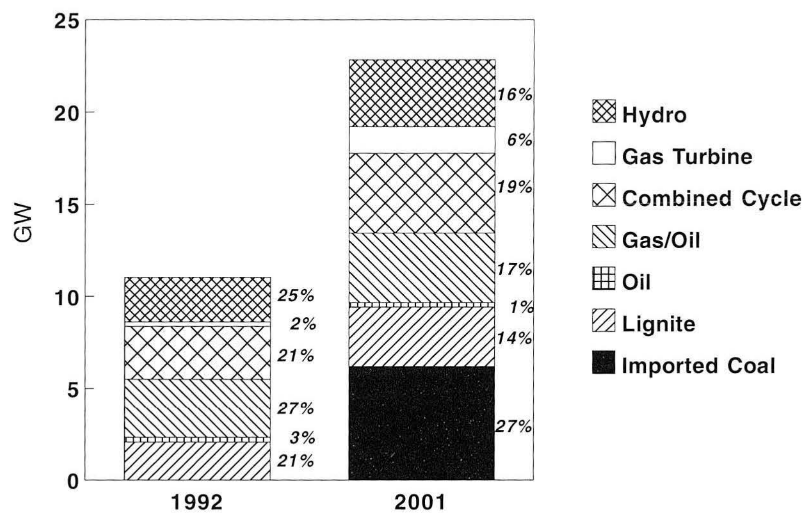

Figure. *Thailand's power development plans (installed capacity).*

Electric Motor Systems in Developing Countries: Opportunities for Efficiency Improvement

S. Meyers, P. Monahan, P. Lewis, S. Greenberg, S. Nadel

Motor systems consume 65-80% of the industrial electricity in developing countries. Drawing on studies of Thailand, India, Brazil, China, Pakistan, and Costa Rica, we found a considerable potential for efficiency gains in various parts of the motor system, including the electricity-delivery system, the motor itself, and driven equipment. There is evidence that new motors in these countries are less efficient than similar motors in industrialized countries, particularly in the smaller motor sizes. For the six countries, the technical potential for electricity savings from high-efficiency motors is estimated at 1.5% to 4.7% of total industrial electricity use. Replacing a failed standard motor with a high-efficiency motor is cost-effective in all study countries. Other components for improving system efficiency include motor speed drive controls, multi-speed motors, properly rewound motors, and more efficient fans, pumps, compressors, and transmission equipment. Substantial savings are also possible from better matching of motor size with the application and improved operation and maintenance. For India, the economic potential for reducing electricity consumption by improving motor system efficiency is estimated at 7% of projected national electricity use in the year 2005.

Although many motor efficiency measures are attractive from a societal perspective, barriers such as information gaps, a scarcity of skilled personnel, capital shortages, lack of local production of high-efficiency components, and high import duties dissuade companies from implementing them. Energy efficiency has historically ranked low on the list of characteristics plant managers look for when purchasing a motor. Low initial cost and short payback times are instead the priority conditions. Policies to reduce the dissonance between societal and consumer perspectives include educating end users on the multiple benefits of efficiency improvements, offering energy audits and other forms of technical assistance, providing incentives through rebates to purchasers and dealers, lowering import duties on high-efficiency equipment, and improving the quality of the electricity supply system. Insights gleaned from the North American experience on overcoming barriers can help developing countries leapfrog the pitfalls of trial and error approaches, but such strategies must be tailored to the unique circumstances of each country.

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Ilumex, Mexico's Residential-Sector Lighting Efficiency Program: A Feasibility Study

J. Sathaye, R. Friedmann, S. Meyers, O. de Buen, A. Gadgil, E. Vargas, R. Saucedo**

The Ilumex project is designed to replace 1.5 to 2 million incandescent bulbs with compact fluorescent lamps (CFLs) over a two-year period in homes in Guadalajara and Monterrey, Mexico. Ilumex will be carried out by the Comisión Federal de Electricidad (CFE, the Mexican electric utility). Program financing will consist of internal CFE funds, a loan to CFE by the World Bank, and grants from the Global Environment Facility of the World Bank and the Norwegian government. Approximately half the funds will become a revolving fund to expand the Ilumex program to the rest of Mexico's 15 million electrified households.

The U.S. Agency for International Development sponsored LBL and the International Institute for Energy Conservation to prepare a feasibility study of Ilumex for CFE to submit to the World Bank. LBL was entrusted with designing and managing a household survey and performing the economic benefit-cost analysis. CFE provided crucial infrastructural support and input to the survey design and its implementation.

Data from the household survey of 900 homes, conducted by the Centro de Estudios Energéticos under LBL guidance, were analyzed to obtain daily lighting load curves for the residential customers in each city and to determine the technical potential of replacing incandescent bulbs with CFLs. The analysis was performed for three customer groups according to their monthly electric consumption.

Survey results show a large evening (6 A.M. to 11 P.M.) peak demand which is roughly six times larger than the residential lighting demand during the rest of the day (Figure). There also is a small peak between 5 A.M. and 7 A.M. whose magnitude is just 10% that of the evening peak. Most lamps in these two cities have incandescent bulbs (87% in Monterrey and 97% in Guadalajara). About 85% of fixtures could accept CFLs. The largest number of fixtures were in the bedroom (about 38%), followed by the kitchen and bathroom (about 14% each). If Ilumex targets physically replaceable 40-100-watt incandescent bulbs that are used at least four hours per day, 1.7 million replacement opportunities exist (or about one-sixth of total lights in the homes). If the utility targets 2-hours-per-day lamps, 3.7 million replacement opportunities exist. If the utility reaches its goal of 1.5 million CFLs, it could defer about 78 MW of capacity and save about 135 GWh annually in Guadalajara and Monterrey. About 93% of households expressed an interest in using CFLs.

The economic and financial analyses show that CFLs are economically feasible for Mexico, the utility, and the average customer as long as they last a certain minimum number of hours. Because of subsidized residential electric tariffs (in particular to small users), the utility company must also share some of its benefits with the smallest users. Net present value of benefits to society was estimated at about $430 to $570 million over the 7.6 years the CFLs would last.

Extrapolating the results to a Mexico-wide program implies a technical potential of 50 million CFLs, equivalent to 4 GW of capacity, 2.2 TWh annual generation savings, and a net national benefit of 1.1 billion dollars.

Current Ilumex program design calls for the utility to share half of the cost of

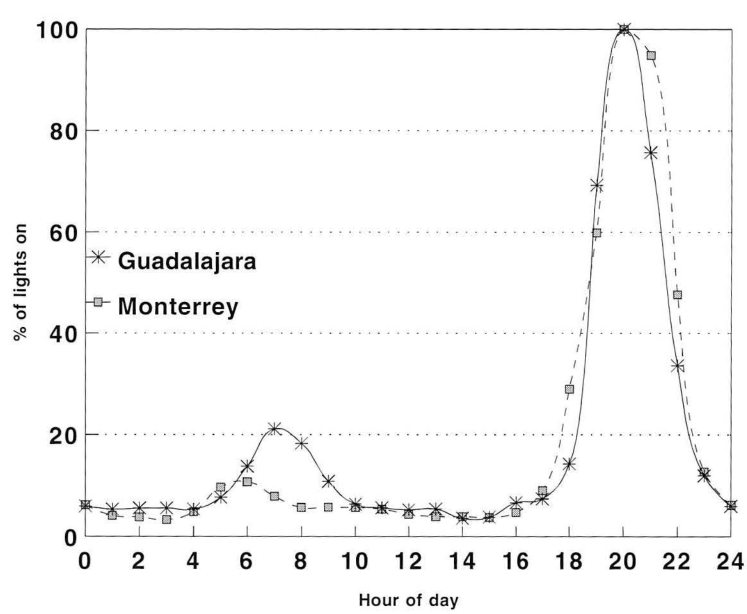

Figure. *Time of use of lights.*

*Comisión Federal de Electricidad, Mexico City, Mexico the CFLs as well as implementation costs. The utility will focus program efforts on smaller consumers and lamps that are used at least 4 hours per day. This ensures that all customers using more than 50 kWh/month have at most a two-year payback.

Future work will entail publishing two papers, one on the survey and the other on the economic analysis. We will also continue to study survey results to examine appliance saturation and time-of-use and compare these with the data for lighting. We will disaggregate these results into three customer classes according to their electric consumption levels.

Reference

Sathaye J, Friedmann R, Meyers S, de Buen O, Gadgil A, Vargas E, Saucedo R. *Economic Analysis of Ilumex, A Project to Promote Energy-Efficient Residential Lighting in Mexico.* Lawrence Berkeley Laboratory Report No. LBL-34877, 1993.

Household Energy Use in Urban Venezuela

M.J. Figueroa, J. Sathaye

Following the methodology of a previous LBL study of household energy use in the city of Caracas, we performed a comparative analysis of surveys conducted in four major Venezuelan cities: Maracaibo, Valencia, Mérida, and Barcelona-Puerto La Cruz. The level of electricity consumption in three of the cities was found to be higher than that of Caracas, reflecting the impact of warmer climates and lower energy prices. Electricity consumption in Venezuelan urban households is remarkably high compared to households in analogous Latin American countries and even in industrialized nations. In Maracaibo, an average household consumes more electricity per year (9300 kWh) than an average household in New Orleans, LA (8950 kWh), which has a similar climate and a higher saturation of electric appliances per household.

The four surveyed cities have had similar patterns of urban development. The use of modern fuels is widespread: the surveys found no use of biomass and a negligible amount of kerosene for cooking. LPG and natural gas are the main fuels used. LPG is the fuel choice of low-income households in all cities except Maracaibo, where 40% of low-income households use natural gas. Appliance penetration is high across income categories. In almost all cities surveyed, appliances such as televisions and refrigerators have reached saturation (100%).

We have identified the major reasons for the high level of energy consumption in Venezuelan urban households: low energy prices, inefficient appliances (refrigerators, air conditioners) currently on the market, inappropriate dwelling design and construction practices, year-round warm climate, lack of vegetation and green areas in the cities, which exacerbates the heat island effect, lack of public information and awareness of ways to reduce electricity use, and lack of institutional support for energy conservation and efficiency programs.

Reform of energy-pricing policies is currently being implemented in Venezuela as part of a set of policies aimed at economic restructuring. Other actions to improve energy efficiency in Venezuela's residential sector include efficiency standards for appliances, appliance labeling, greater public awareness of energy-efficient technologies, building standards, required tree planting for new developments, and community pilot demonstration programs for specific technologies.

Reference

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Energy Conservation in China's Highway Transport Sector

J. Sathaye, S.Y. Zhang, J. He, A. Zhang*, Q. Xu**

Fuel intensity in the Chinese highway transport sector is 15-25% higher than in developed countries. The major causes of this disparity include:

- use of less fuel-efficient engines in trucks and buses;
- high percentage of medium-sized trucks in use compared to heavy-duty and light-duty ones;
- extensive use of gasoline in trucks and buses, whose fuel intensity is higher than that of diesel fuel;
- scarcity of paved highways in China—only 27% of all roads in 1991—which increases fuel use; and
- a rudimentary highway transport management system which results in poor service and lower actual load-to-truck capacity.

This project evaluates the economic feasibility of substituting diesel engines for gasoline in China's truck and bus fleets. The analysis indicates that from a societal perspective, the replacement of gasoline engines with diesel-run engines would not only be more energy-efficient, but would also be cost-effective. Refineries would, however, suffer losses due to retooling and the increased cost of producing diesel.

As with any large-scale conversion effort involving many players—manufacturers, refiners, transport authorities, and individual truck owners—coordination of the process is key to the success of the effort.

Well-formulated policies and regulations concerning taxation and bank credits would be needed so that they are consistent with national goals.

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