Lawrence Berkeley National Laboratory

Summer 1999

Environmental Energy Technologies Division **News**

Air Quality · Advanced Technologies · Building Technologies · Energy Analysis · Indoor Environment

Energy for Industry

Special Issue

Responsible for about 40% of global energy demand, the industrial sector is the world's dominant energy user followed by buildings, transportation, and agriculture. Berkeley Lab's Environmental Energy Technologies Division approaches industrial energy issues from a multitude of perspectives, ranging from basic R&D to understanding the driving forces behind historical or future industrial energy-use patterns. Our work encompasses basic as well as high-tech industries and examines the economic and environmental dimensions of industrial energy use and the potential for new technologies to improve the quality and efficiency of industrial processes and the health and productivity of workers.

In addition to front-line research, Berkeley Lab staff possess an interdisciplinary set of talents and resources for analysis and modeling. The Division can also apply sophisticated research instruments, and partner with facilities and shops in the rest of Berkeley Lab to develop or refine manufacturing technologies.

Industry-Focused Projects in EETD

EETD has developed nondestructive techniques for testing paper quality without interrupting the manufacturing process (page 3). Through rapid detection of manufacturing problems, laser ultrasonics can save energy and time while minimizing the volume of defective product.

Fundamental research in our Combustion Group has led to the development of two new gas-burner technologies that offer better flame quality, more complete combustion, reduced energy costs, and lower emissions (page 4). Promising applications identified across a wide range of scales and applications include furnaces and gas turbines for electric power production.

The Applications Team has discovered considerable energy-efficiency potential in high-technology industrial settings, such as cleanrooms and laboratories (page 11). Efforts have focused on developing a design guide for laboratory-type facilities and identifying opportunities for savings through a holistic performance-assurance approach. The work has also involved developing a high-efficiency fume hood for laboratories.

Other EETD work focuses on the interior environment in which industrial processes occur—and where both human health and equipment performance can be at stake. A project performed by our Indoor Environment Department has evaluated the risk of electronic circuit failures induced by small airborne particles that defy conventional air-filtration systems (page 5). As the trend toward miniaturization continues, electronics become increasingly susceptible to short circuits caused by small particles.

Carbon monoxide in the workplace is a hazard whose mag-

continued on page 2

In this Issue

The mission of the Environmental Energy Technologies Division is to perform research and development leading to better energy technologies and market mechanisms to reduce adverse energy-related environmental impacts.

continued from page 1

nitude is not well known. A new occupational sensor developed in partnership with QGI can help alert workers and managers when CO levels are too high (page 13).

In many cases we work directly with individual firms to improve their products. In a recent example, researchers from Berkeley Lab's Engineering Division and EETD assisted Visteon Automotive Systems in developing a new generation of energy-efficient automobiles. The work focused on reducing vehicle heating and cooling requirements through the use of advanced insulation and window systems (page 6).

Our analytical work includes in-depth sectoral studies of energy-savings potential in industry, exemplified by the Energy Analysis Department's assessment of the U.S. steel industry. They found that implementing 47 technologies and process improvements could lead to a cost-effective 18% energy savings (page 8).

To help address the fact that national and international industrial energy-use patterns are poorly understood, Berkeley Lab is home to the International Network of Energy Demand Analysis in the Industrial Sector (INEDIS). The project links research groups from around the world that are collecting data to establish solid baselines, analyze trends, evaluate policies, and assess the potential for new technologies (page 9).

Research at Berkeley Lab also explores the special problems and needs of developing nations, which use more than half of the world's industrial energy and collectively exhibit a demand growth rate three times that of industrialized countries. A recent project examined the role currently and potentially played by development banks in industrial energy efficiency. Our in-depth case study from India pinpointed the opportunities and barriers (page 10).

With an eye to ensuring that new technologies reach widespread use, we address the "downstream" processes of technology diffusion and market transformation. This is exemplified by our Industrial Policy Group's current efforts to develop collaborative approaches to improving decisionmaking and operations and maintenance infrastructure in the compressed air, paper and pulp, and industrial pumping marketplaces (page 12).

Finally, on page 14, EETD research explores how materials end-use efficiency can indirectly help reduce energy demand in the industrial sector.

—Evan Mills

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Lawrence Berkeley National Laboratory

Ernest Orlando Lawrence Berkeley National Laboratory is a multiprogram national laboratory managed by the University of California for the U.S. Department of Energy. The oldest of the nine laboratories, LBNL is located in the hills above the campus of the University of California, Berkeley.

With more than 3,800 employees, LBNL's total annual budget of nearly $330 million supports a wide range of unclassified research activities in the biological, physical, computational, materials, chemical, energy, and environmental sciences. The Laboratory's role is to serve the nation and its scientific, educational, and business communities through research performed in its unique facilities, to train future scientists and engineers, and to create productive ties to industry. As a testimony to its success, LBNL has had nine Nobel laureates. EETD is one of 13 scientific divisions at Berkeley Lab, with a staff of more than 300 and a budget of $36 million.

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Laser Ultrasonics for Paper Quality

How can paper's strength and flexibility be measured without touching it? What's more, how can it be done when the paper is moving at 30 meters per second (65 miles per hour)?

EETD's Paul Ridgway and Rick Russo are developing a laser-based ultrasonic technique to answer these questions. This technique measures paper's mechanical properties nondestructively while it's on the papermaking machine, or "web."

Because paper's strength, fiber orientation, and flexibility cannot be measured while the sheet is moving on the web, industry analysts rely on measurements of samples cut from the ends of large paper rolls. The delays that result from having to adjust the process variables cost manufacturers significant time and money. A monitor of paper strength installed on the web would allow real-time feedback control of the process, resulting in valuable savings in feedstock and energy. Such a strength sensor must make nondestructive measurements on paper moving at production speeds. This is the goal of the "Laser Ultrasonics for Paper" project.

Ultrasound is used to probe fiber orientation and to test tensile and compressive strength, bending stiffness, and other important mechanical properties of paper. Ultrasonic analysis using contact transducers is gaining credibility in the papermaking industry; in fact, contact-based techniques for measurement on moving paper have been in development for over 25 years. Commercial systems are just now becoming available for heavy paper grades; however, the pressures required to operate contact transducers damage lighter grades of paper.

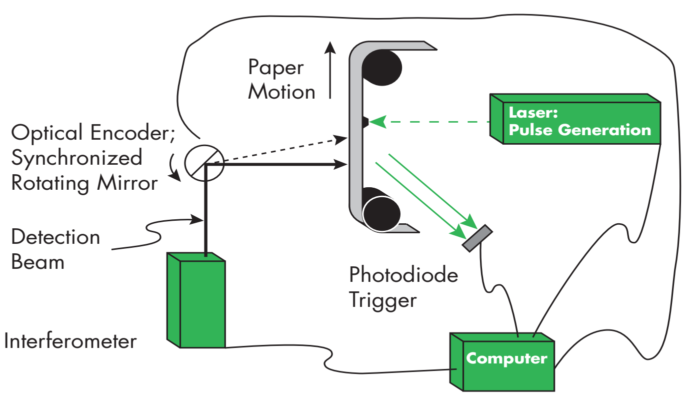

Figure 1. Schematic of the experimental system.

Laser Ultrasonics (LUS) is a noncontact, nondestructive method that recently has been used to analyze paper's mechanical properties. A short (less than a microsecond) pulse of laser light generates ultrasonic waves by either a thermal expansion or an ablation shock wave or both. The ultrasonic wave propagates along the paper sheet and is detected at a known distance (several millimeters) using a noncontact interferometric technique. The time-of-flight of the wave over the known distance gives the propagation velocity of the wave. The wave velocity is theoretically related to elastic properties, which in turn are empirically related to strength properties.

Laboratory Simulation

Shown schematically in Figure 1, the LUS system for moving paper is composed of three parts: a "web simulator" and generation and detection systems. A photograph of the system is shown in Figure 2. The web simulator, designed by Berkeley Lab engineer Sam Mukherjee and built by machinist Steve Ferreira, rotates a paper belt at up to 30 m/sec. The generation system consists of a pulse Neodymium Yittrium Aluminum Garnet (Nd-YAG) laser and associated optics.

The key components of the detection system are a commercial Mach-Zender interferometer, a rotating mirror, and control electronics. The rotating mirror moves the interferometer probe beam with the paper, effectively stopping the paper motion with respect to the detection spot. An optical encoder is used to track the mirror's rotational position. An adjustable delay circuit, designed and built by Berkeley Lab engineer Paul Barale, triggers the firing of the generation laser pulse so that the ultrasonic wave is detected when the detection beam is in position on the paper surface. Measurements are made on paper moving at up to 30 meters per second, the highest production speeds used in the papermaking industry.

Further development goals include optimizing laser generation wavelength and pulsewidth; extending the method to measure ultrasonic velocities in all directions in the plane of the paper sheet; interfacing the system to a computer for control, data acquisition, and signal analysis; and eliminating the rotating mirror.

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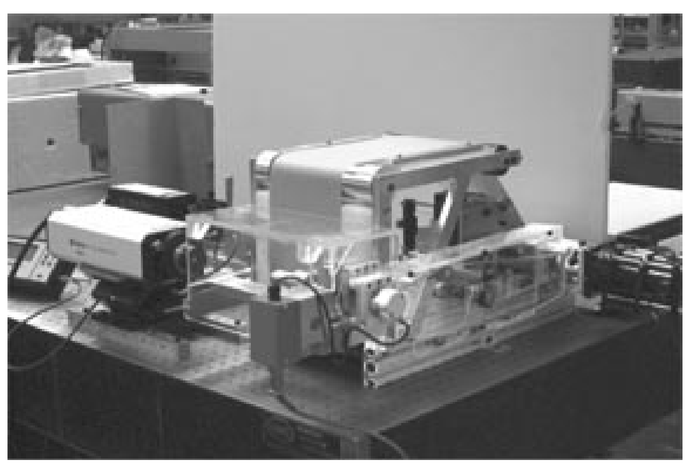


Figure 2. The apparatus.

Low-Emissions Burners

Combustion is a critical cross-cutting technology for industrial processes, electric power production, material synthesis, space and water heating, and transportation. Maximizing the benefit of combustion while minimizing emissions of harmful pollutants poses large technological challenges.

An EETD team has been conducting fundamental research into the nature of combustion and its interaction with turbulence that exists naturally in all combustion devices. It has patented two new concepts that may have a significant impact on the designs of next-generation, low-emission burners. Both technologies exploit lean premixed combustion, which is fast becoming the technology of choice for reducing oxides of nitrogen (NO_X) emission and increasing combustion efficiency. Initial laboratory studies have shown the two new burner technologies to be highly effective, producing emissions far below some of the most stringent clean-air standards, with no particulate emissions.

One technology, an inner-ring flame stabilizer, was developed for a National Aeronautics and Space Administration project to investigate open-flame behavior in the absence of buoyancy. The other, a low-swirl burner, was developed as a versatile laboratory tool for studying turbulence-flame interaction processes.

The Ring Stabilizer

The ring stabilizer is an extremely simple device that can be fitted inside a burner port. This ring maintains a stable premixed flame under both fuel-rich and -lean conditions. Unaffected by turbulence, the stabilizer helps produce more complete combustion, thereby lowering emissions of carbon monoxide (CO) and hydrocarbons (HC), while its ability to support ultra-lean premixed combustion lowers the production of NO_X.

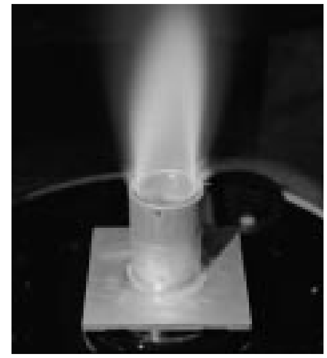
The Low-Swirl Burner

All conventional swirl burners are high-swirl burners. In 1991, EETD's Combustion Group developed a prototype low-swirl burner that uses small air jets to swirl the premixed flow inside the burner tube. The low-swirl technology leaves the center core flow undisturbed and produces a divergent flow above the burner exit. Flow divergence provides a highly effective means for stabilizing lean premixed combustion because it enables the flame to settle where the local velocity equals the flame speed. A vane swirler (with angled guide vanes) has been developed that eliminates the need for air jets and is much more suitable for commercial use because of its simplicity.

Low-swirl burners with vane swirlers offer the same ability to support ultra-lean premixed combustion as their air-jet predecessors. A unique feature of the low-swirl burner is that the flame is completely detached from the burner such that the burner receives almost no thermal stresses. In the photograph, a plastic low-swirl burner is firing at about 16 kW.

Potential for Commercialization

The flame stabilizer ring insert and the low-swirl burner are in various stages of testing in laboratory studies to establish their potential for commercial use. When a multiport ring burner was fitted to a domestic forced-air furnace, the resulting emissions



A burner built from inexpensive plastic pipe shows the adaptability of the low-swirl burner (left). The ring stabilizer keeps the flame steady (right).

were well below air-quality standards for NO_X and CO, and the system efficiency was increased by 5%. A low-swirl burner tested in a 15-kW spa heater produced the same results.

The low-swirl burner has been successfully scaled to furnace applications. In tests conducted in a furnace simulator at the University of California (Irvine) Combustion Laboratory, a 10-cm burner was operated with an output of up to 600 kW. Emissions were low: at 600 kW—typical burners operate from 10kW to 100 MW—the burner emitted only 12 parts per million (ppm) of NO_X, 20 ppm of CO, and <1 ppm of HC. The test conditions will be extended beyond 1.5 MW. Recently, the potential of using the low-swirl flame stabilization method in gas turbine combustors was confirmed at the Solar Turbines test facility in San Diego. Successful firing of a "low-swirl injector" prototype under typical gas turbine conditions shows that this new combustion concept will also be applicable to power generation systems.

These combustion technologies offer direct and simple means to achieve ultra-low emissions. In addition to their low emissions and high efficiency features, the main economic advantage will be their potential for significant first-cost savings compared to current low-NO_X burners that use complicated processes such as flue gas recirculation, selective catalytic reduction, or sophisticated burner materials. Add to this simple flow controls and the ability to support stable, lean premixed flames free of loud rumble and instabilities. Operating with high combustion efficiency, a high turndown of at least 15:1 (turndown is the ratio of the highest operating power to the lowest operating power), and low pressure drop, the burners can be scaled to different capacities to meet the varied needs of commercial and industrial production.

—Robert Cheng

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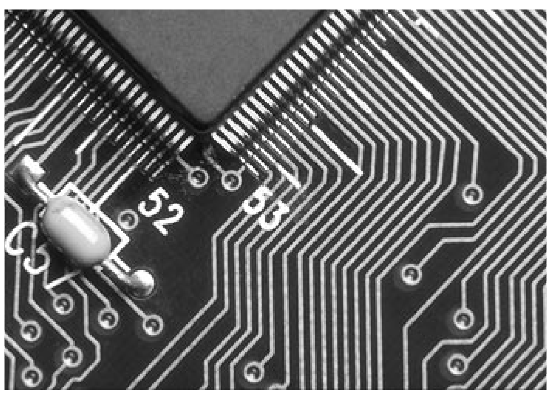
Avoiding Particle Deposition in Small-Scale Electronics

The deposition of particles from indoor air on circuit boards in electronic equipment reduces the electrical isolation between conductors, sometimes causing electrical short circuits. This is the finding of EETD researchers, who believe that, over time, deposited particles may be responsible for failures in telephone-switching and other electronic equipment. Circuit failures caused by indoor air pollutants cost U.S. telephone offices roughly $200 million annually, but given the amount of electronic equipment in use throughout the U.S., the overall total costs may be much higher. Protection of electronic circuits against indoor air pollutants is an important issue for industrial economies, which increasingly rely on smaller components in information-processing equipment. As miniaturization increases and electrical conductors are placed closer and closer together, the products are increasingly susceptible to this problem.

To keep spaces clean, air-handling systems remove large (2 to 20µm) particles, including fibers, which are generated by mechanical wear on materials or derived from biological sources. Smaller particles (<2µm), generated by combustion or photochemical gas-to-particle conversions, often pass through filters and are carried into buildings with outdoor air but may not be removed efficiently by the air filters.



Risks to Industry

Such fine-mode particles produce a greater threat to indoor electronics because they can be deposited on both vertical and horizontal surfaces. Moreover, when voltage is applied, electrical forces enhance the deposition on circuitry. Above all, such particles tend to be hygroscopic—i.e., able to attract or absorb moisture from the air. As much as half the fine-particle mass in a building is from hygroscopic particles. When the environment reaches a critical relative humidity (roughly 50 to 65%), the deposited particles deliquesce (become liquid by absorbing moisture) and become electrically conductive.

Some of the electrical conductors in modern electronic equipment, like the "legs" of surface-mounted chips that connect the chip to the circuit board, are directly exposed to ambient air in the workplace. When particles accumulate, producing bridges between adjacent conductors, and relative humidity runs high, electric current may leak or produce short circuits.

Discovering the Nature of Deposition

Andres Litvak, a graduate student working under the guidance of Ashok Gadgil and Bill Fisk of the Indoor Environment Department, conducted an experimental study with a view toward better understanding particle deposition and failure rates of electronic circuitry. The findings will allow the prediction and prevention of failure rates (as a function of ventilation and filtration scenarios).

Eighteen dummy surface-mounted chips and six television sets were installed in an exposure chamber. The chips were connected to surface trace conductors on circuit boards by their conductive legs, then mounted (some vertically and others horizontally) in an environmental chamber. A range of voltages was then applied to the circuits. After careful cleaning of the circuits, the electrical isolation between the legs was measured as a function of the relative humidity of the surrounding air. Particle concentrations inside the chamber were then increased using a system that generated ammonium sulfate particles (average diameter of 0.48 µm) and were maintained at 500 times greater than "normal" for 281 hours, yielding the equivalent of 16 years' worth of normal particle exposure.

Results

Surprisingly, no television malfunctions were observed at any relative humidity. The lack of deterioration may possibly be explained by the elevated temperatures inside the television sets, which prevented the relative humidity from exceeding the critical relative humidity for deliquescence. Also, the spacing between electronic conductors in the TV sets was larger than that in most modern electronics.

On the circuit boards, the highest levels of accumulated particles were observed between the legs of surface-mounted chips with a voltage differential—especially on the sharp edges and in the sharp bends of the legs. However, particle accumulation was also observed between legs that were grounded. Particles bridged adjacent legs, but in uneven patterns. Fibers were observed within some of the finer agglomerations of particles, apparently facilitating the formation of bridges between conductors.

Electrical isolation between the adjacent legs of chips decreased after particle exposure. The isolation between legs with a differential voltage decreased by approximately three orders of magnitude. In some instances, the electrical isolation decreased to a point known to cause failures of electronic circuits. On one circuit board, a short circuit caused visually obvious damage. Researchers proposed a change in the geometries of the legs that eliminated the sharp bends in the conductors associated with particularly high localized particle deposition.

As equipment shrinks to meet new demands from industry, particle deposition will cause a certain percentage of equipment failure. Understanding this process under varied conditions can help avoid catastrophic and costly failures in an industry that will be increasingly developing unique electronic solutions.

—Ted Gartner and William Fisk

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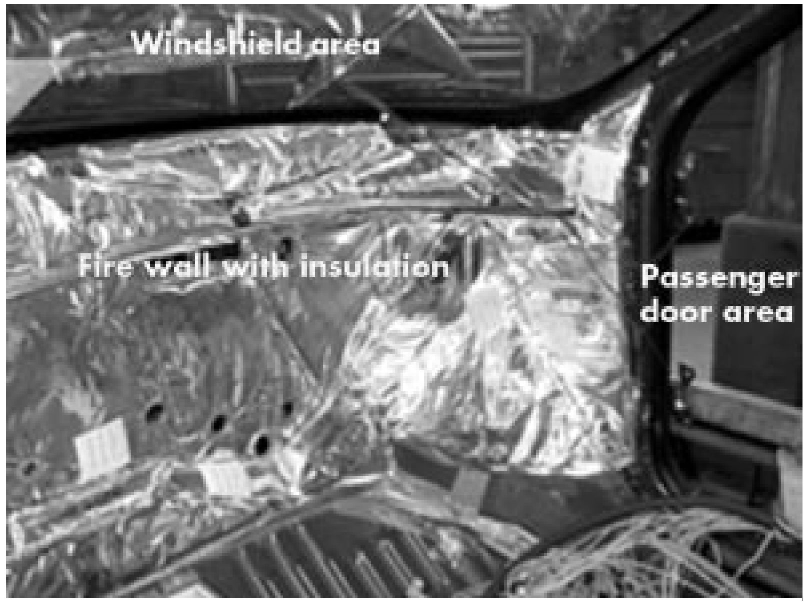
This research is sponsored by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy.

Thermal Management for Automobiles

Visteon Automotive Systems, the Environmental Energy Technologies Division, and Berkeley Lab's Engineering Division are collaborating on a research project to create the world's first thermally insulated car. With EETD-developed insulation inside body panels and insulated window units, the thermally insulated car will have better gas mileage than a conventional car and stay cooler in the summer and warmer in the winter.

The aim of this automotive thermal management project is to develop technology that helps reduce a car's total weight by 40%. That is the ultimate goal of Partnership for a New Generation of Vehicles (PNGV), a federal/private-sector research collaboration that this project is part of. The 40% weight reduction, along with other improvements, will raise the gas mileage of a Taurus to 80 miles per gallon without a loss of performance or decreased occupant comfort.



Researchers designed customized gas-filled panels to fit the car's interior.

This is the first time a car manufacturer is studying thermal insulation for passenger comfort. Adding insulation to the car allows its heating, ventilation, and air conditioning system to be smaller, reducing the car's weight and improving mileage. Insulation can also extend the range of electric vehicles by reducing the load on their batteries. The insulation and window film reduce heat gain or loss, smoothing out the temperature peaks and troughs inside the car, keeping it comfortably cooler or warmer, and reducing material degradation caused by ultraviolet light.

Project researchers are collaborating with Visteon. The Thermal Management Project is associated with the United States Council for Automotive Research (USCAR), the research consortium funded by Daimler-Chrysler, Ford, and General Motors to strengthen the domestic auto industry's technology base, as well as the PNGV initiative.

In February, Visteon sent the Berkeley Lab research team a factory-new white Taurus. The car was stripped down to sheet metal within two hours by a technician.

The windshield was modified by applying a spectrally selective solar-control film to the inner surface. The Berkeley Lab team fabricated double-pane insulated glazing units for the side windows. The insulated glazing units have spectrally-selective film on the inner surface of the outer pane and low-emissivity film on the inner surface of the inner pane. The solar control film consists of multilayer thin-film plastics, which create a narrow-band-pass filter that rejects ultra-violet and infrared wavelengths. The result is much less heat gain into the interior of the car and less degradation of interior surfaces. The low-e film suppresses radiative heat loss, helping to maintain comfortable conditions in the passenger compartment in both hot and cold weather.

Gas-Filled Panels

Berkeley Lab's patented gas-filled panel (GFP) insulation has a high performance-to-weight ratio. Adding two to five centimeters of insulation increased the weight of the car door by only 120 grams. The weight savings achieved by GFPs over other insulation options allowed the installation of double-pane windows, which were essential to achieve the overall goal of thermal performance.

GFPs use thin polymer-film cellular baffles and low-conductivity gas filling to create a lightweight device with extraordinary thermal insulation properties. GFPs are essentially hermetic plastic bags that can take on a variety of shapes and sizes. GFPs can be up to three times as effective as conventional foam insulation, depending on the type of gas used.

Low-emissivity coatings for residential windows were pioneered by EETD and window manufacturers in the 1970s and 1980s. Spectrally selective low-e coatings reflect far-infrared radiation (for example, the sun's heat), preventing it from warming an interior space. These energy-efficient coatings are now claiming growing shares of the market for residential and commercial building windows.

Berkeley Lab Engineering Division's Deb Hopkins, Daniel Türler, and Phil Rizzo, EETD's Brent Griffith and Howdy Goudey, and technicians in five of the Lab's shops worked around the clock to retrofit the car by their March deadline. Goudey and Rizzo manufactured GFPs in EETD's infrared-thermography lab, a facility designed for developing and testing insulation and window technology [see sidebar on page 7]. With Türler, they installed the panels in the car body.

In this widely collaborative effort, everyone involved had to help out with the production of GFPs; never before had so many panels of the experimental insulation been assembled. Berkeley Lab's Technical Services Division was instrumental in providing technical support as needed. The Plastics Shop made the contoured interior pane of the dual-pane glazing systems installed on the back and side windows; the Coating Shop manufactured customized plastic parts with aluminum coatings; the Refrigeration Shop drained and tuned the car's air conditioner on short notice; and the Carpentry Shop made shipping crates to deliver the modified doors and parts to Detroit.

Hopkins, Türler, and Goudey went to Detroit in March. There they reinstalled the parts in another Taurus. Another team then tested the thermal characteristics of the refit Taurus in an environmental chamber under hot and cold conditions, as well as under driving conditions.

The retrofitted car was also tested in environmentally controlled wind tunnels under driving conditions for hot (55°C) and cold (-18°C) temperatures. The thermal performance of the vehicle exceeded design goals; using advanced insulation and window technologies reduced the vehicle's heating and cooling loads by 80 and 75%, respectively.

With the first phase of Berkeley Lab's work complete, the team plans to use EETD's infrared thermography facility to evaluate the heat flow in the car's interior and refine and improve the design of the insulation.

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Berkeley Lab researchers Daniel Türler and Deb Hopkins at work in Detroit.

The IR Thermography Laboratory

Berkeley Lab's Infrared Thermography Laboratory (IR Lab) conducts detailed experiments on the thermal performance of windows and other insulated systems. Its facilities have also been used to study a variety of other technologies such as lighting, roofing materials, and photovoltaic tiles. During a typical experiment, a specimen is placed between two environmental chambers that simulate a long, cold winter night. Besides generating informative thermal images, the experiments collect several types of quantitative data with high spatial resolution. These data are useful for understanding subtle details in the thermal performance and for validating computer simulations of heat and fluid flows. Thermography experiments in the IR Lab use an infrared imager to produce qualitative thermal images, or thermograms, that help visually interpret how heat is flowing through the specimen. The infrared thermograms are also processed to extract numerical data to perform quantitative thermography that produces a database of the distribution of surface temperatures on the warm side of various specimens. A traversing system is also used to measure the distribution of air temperatures and velocities near the specimen. The IR Lab houses a machine-tool shop area that supports fabrication efforts. Other types of research, such as nondestructive evaluation, are also conducted in the IR Lab.

The IR Lab helps improve the energy efficiency of buildings, appliances, and automobiles by aiding in the development of technologies with high thermal performance and by improving the analysis of complex heat-flow situations. Current areas of interest include improving the edges and frames of windows, validating computer programs that simulate window performance, and analyzing localized surface heat transfer coefficients. Even today's highest-performance windows need improvement because edge heat losses can reduce overall performance by up to a factor of two. Figure 1, an example of hollow and foam-filled vinyl windows, shows that the better-insulated vinyl foam-filled windows lose less heat.

Studies performed by IR Lab researchers have also been used to measure the thermal characteristics of roofing materials. Roof materials that are good reflectors of heat help reduce the need for air conditioning inside homes and small commercial buildings. In Figure 2, thermograms of photovoltaic roof tiles help determine the effect of tile design on solar cell operating temperatures (cooler photovoltaics are more efficient).

—Brent Griffith

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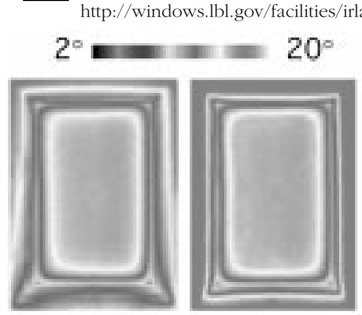


Figure 1. Thermograms of hollow (left) and foam-filled (right) vinyl windows, showing higher interior surface temperature and reduced heat loss in the latter.

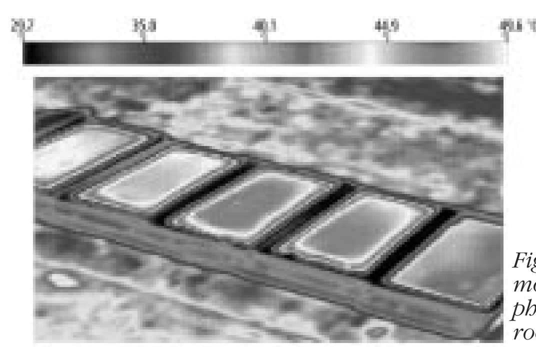


Figure 2. Thermograms of photovoltaic roof tiles.

Energy-Efficiency Improvements for the U.S. Steel Industry

According to a first-of-its-kind study by EETD researchers, the U.S. iron and steel industry could cost-effectively reduce its energy use by 18% while producing the same amount of iron and steel. The reduction in energy use would result in a 19% reduction in emissions of greenhouse gases, according to the study, which examined the steel industry's current practices and the potential costs and savings of adopting 47 retrofit technologies.

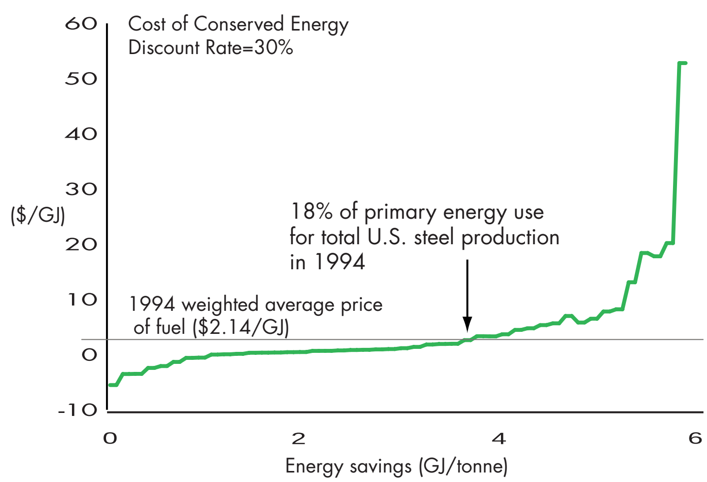
Ernst Worrell, Nathan Martin, and Lynn Price, of Berkeley Lab's Environmental Energy Technologies Division, authored the study. It is the first in a series of assessments of various U.S. industries and a product of the team's effort to develop a national and international database of industrial energy use. With the help of experts throughout the world in the International Network of Energy Demand In the Industrial Sector (INEDIS) network (see following article), EETD's study is one of the first to assess the cost-effectiveness of technologies to improve the industry's energy efficiency. Improving energy efficiency of the steel industry not only reduces its energy costs and pollutant emissions, but can also make the industry more competitive.

Among the world's eight largest steel-producing nations, South Korea, Germany, and Japan have the most energy-efficient steel industries. South Korea's industry is the most energy-efficient, using fewer than 20 gigajoules (GJ) per metric ton of steel in 1994 (the higher the energy intensity, the lower the energy efficiency of the industry). The U.S. stands at slightly over 25 GJ/metric ton (1994). Reviewing the industry as a whole, U.S. steel plants are relatively old and production has fluctuated dramatically in the recent past. Steel production in the U.S. peaked at 136 million metric tons in 1973, and then fluctuated between 1974 and 1982, when production crashed to 68 million metric tons, due to weakened global demand for steel as well as the closure of older, less competitive mills. Except for a couple of periods of decline, production began to grow slowly again and by 1998 reached 98 million metric tons.

Between 1958 and 1994, the U.S. steel industry modernized—closing open-hearth furnaces, increasing use of continuous casting, introducing new energy-efficient electric arc furnaces—and improved its energy efficiency. Even so, additional technologies exist to reduce energy use for steel production. The report's 47 energy-efficient measures range from technologies that are specific to the steel industry to general process improvements that are widely adaptable to different industries. Examples of the former category include direct fuel injection in the blast furnace, scrap preheating in the electric arc furnace, and thin slab casting. General process measures include improved process maintenance and the use of an energy-monitoring and control system to regulate a steel plant's energy use.

For example, thin slab casting consolidates the casting and hot rolling steps of steel production into one, dramatically reducing energy use by 5 GJ per metric ton, due to energy and material savings. Although investments are estimated at $135 per metric ton, production costs are reduced by $25 to $36 per metric ton. This results in a simple payback period of just over three years. Several U.S. plants use this technology, but many more could implement it.

The first supply curve for energy savings in the U.S. iron and steel industry. The figure shows that using a hurdle rate of 30% for investments, we can improve energy efficiency cost-effectively by 18% by adopting all commercially available technologies that fall below the weighted average price of fuel.



Many of the other technologies described in the report are in a similar state of deployment: they are used in steel industries throughout the world, including the U.S., but the wider use of some of these technologies in the U.S. would help improve competitiveness and energy efficiency.

EETD's researchers ranked the individual technologies and practices, which were organized in a so-called energy-savings supply curve, depicting the potential of energy efficiency improvement as a function of the costs to achieve these savings (see Figure). An energy-savings supply curve can schematically represent information on the selected practices and technologies, as well as help to identify low-cost opportunities.

The study team plans to investigate the energy efficiency of other U.S. industries, including cement, pulp and paper, chemicals, and petroleum refining. They are also working to assess energy-efficient measures that are applicable to many different industries, such as steam production and distribution systems.

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"Energy Efficiency and Carbon Emissions Reduction Opportunities in the U.S. Iron and Steel Sector," Berkeley Lab Report No. LBNL-41724, is available from Ernst Worrell and Lynn Price or at http://eetd.lbl.gov/ea/IEUA/IEUA.html.

This research is sponsored by the U.S. Environmental Protection Agency.

INEDIS: Global Network for Industrial Energy Analysis

The objective of the International Network for Energy Demand Analysis in the Industrial Sector (INEDIS) is to strengthen the analysis of industrial energy use. Energy-use patterns in the industrial sector, the largest global energy user, are poorly understood. INEDIS, begun in 1998, consists of research groups from various countries who are collecting data on industrial energy demand and greenhouse gas emissions, and conducting trend analyses, policy evaluations, and technology assessments. The European Commission (ENRICH-programme, DG-XII) and Berkeley Lab (USA) have provided seed funding, while a number of individual projects have provided funding to collect and analyze industrial energy use for specific countries.

Within the manufacturing sector, a subset of industries exists in which the energy required to produce a unit of economic output is three to five times greater than the average energy required for industry overall. In this subset of energy-intensive industries, raw materials are transformed or converted into intermediate and finished products, accounting for 40 to 80% of manufacturing energy use depending on the country. Efficiency or technology improvements that can reduce energy demand in these key raw-materials industries will play an important role in reducing global industrial energy demand and greenhouse-gas emissions.

INEDIS focuses on a number of specific industrial sectors as well as cross-cutting issues. Network participants compile, exchange, and analyze data on energy use and efficiency for particular industrial subsectors (see Table 1).

Global Energy Demand Database

Types of quantitative data and information collected by INEDIS include national time-series data of energy consumption by fuel, output by process type and product types, and the shares of key production technologies. The database also contains data on trade, economic output, and factor costs (e.g., energy prices, labor costs). The database will be accessible to all network members through the World Wide Web. An electronic discussion group on industrial energy issues is available for members.

Special Topic Reports

The strength of a network is its ability to bring together researchers, analysts, and industrial professionals to engage in collaborative analyses of key industrial topics, including international assessments of energy efficiency in industry, energy-efficiency research and development, trends in energy use in sector-specific process technologies, energy-efficiency policy effectiveness, and industrial ecology.

Participating Organizations

The institutes that initiated INEDIS have developed internationally accepted methodologies for comparisons of energy efficiency and energy-efficiency developments. Around 20 institutes and international organizations are currently part of INEDIS (see Table 2). The network organized the recent International Workshop on "Industrial Energy Efficiency Policies: Understanding Success and Failure" in The Netherlands; a copy of the proceedings is available.

INEDIS is interested in adding other members to increase its geographical coverage and to strengthen its industrial energy analysis work.

Visiting Researchers

INEDIS researchers are encouraged to collaborate on industrial-sector analyses and to spend time at other INEDIS organizations to exchange data and information. Over the past two years, EETD has hosted visiting researchers from Brazil, China, Italy, Mexico, The Netherlands, and Portugal and will be hosting a visitor from South Korea in the near future. LBNL scientists have collaborated on various projects with the visiting researchers.

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This research is supported by the European Commission, Lawrence Berkeley National Laboratory, and the U.S. Environmental Protection Agency.

Table 1. Focus areas of INEDIS data-collection effort.

Sector	Area of Focus
Metals	Iron, steel, aluminum
Fuel conversion	Petroleum refining, coke production
Building materials	Cement, glass, bricks, tiles
Forest products	Pulp, paper
Chemicals	Chlorine, ethylene, ammonia
Light industries	Food processing, metals fabrication, other light industries
Cross-cutting	Energy efficiency and CO_2 mitigation policies, cross-cutting technologies (e.g., cogeneration, motors)

Table 2. Current participants in the INEDIS network.

National Institutes	
Lawrence Berkeley National Laboratory	U.S.
Utrecht University	Netherlands
Universidade de Coimbra, ISR	Portugal
Fraunhofer, Gesellschaft ISI	Germany
Lund University	Sweden
Federal University of Rio de Janiero	Brazil
TATA Energy Research Institute	India
Canadian Industry Energy End-Use Data and Analysis Center	Canada
Department of Minerals and Energy	South Africa
Inha University	South Korea
Universidad Nacional Autónoma de México	Mexico
Polytechnic University Bucharest UNESCO Chair	Romania
AKF	Denmark
ETH Zürich	Switzerland
International Organizations	
Asia Pacific Energy Research Centre	APEC
International Energy Agency	OECD
World Energy Efficiency Association	Global

Development Banks and Industrial Energy Efficiency in India

Development Finance Institutions (DFIs) were established in 1955 to provide funds to large, medium, and small industry in India. They finance new industrial projects as well as expansion, diversification, and modernization of existing industrial enterprises. In 1997-98, for instance, the Industrial Development Bank of India (IDBI) and the Industrial Credit and Investment Corporation of India, the two largest DFIs, provided $12 billion worth of financing. In recent years, DFIs have been active in managing and lending for industrial energy-efficiency and environmental projects. Because of their role in lending for industrial institutions, the DFIs are in a position to transform the market for industrial energy efficiency and environmental pollution-control activities.

We evaluated the potential role for IDBI in lending for energy efficiency and environmental pollution-control activities. The Asian Development Bank had provided IDBI a $150 million loan for the Industrial Energy Efficiency Project at the request of the Government of India to improve energy efficiency in the modernization and expansion of industry. The primary energy-efficiency criterion for selecting industrial projects was that the modernized or expanded plant show at a minimum an energy-efficiency improvement of 18%. In addition, a technical assistance project accompanied this line of credit to IDBI. This project formed the basis of our evaluation.

The project's main activities were to evaluate the investment potential for energy efficiency/environmental management (EE/EM) activities or projects in ten industrial sectors and to recommend ways to strengthen IDBI's institutional capacity, policies, and procedures for EE/EM lending on a regular and organized basis. The evaluation of these industrial sectors revealed an investment potential, with a payback period of less than four years, that exceeded $1 billion (Rs. 45 billion). The IDBI evaluation identified many areas where establishing an energy and environmental center would accelerate efficiency investments.

The consultant's team also conducted in-house seminars, overseas training programs, and site visits to steel, paper, and aluminum plants; organized outreach workshops for industry; and provided bibliographic information for the IDBI library.

The technical assistance project was managed by a U.S. company, Energy Resources International, with primary responsibility for the technical aspects covered by Berkeley Lab and Dalal Consultants and Engineers Ltd. of India. Indian sector specialists were hired to study the potential for energy-efficiency improvement and environmental management.

Findings of the project reveal a need to (1) use EE/EM indicators during IDBI's appraisal, approval, and monitoring of projects, (2) increase the EE/EM information resource base—in-house and out-of-house EE/EM experts, handbooks, and computerized data bases—that IDBI staff can access, and (3) increase awareness of EE/EM components among industrial borrowers. The sector studies show that there is at least a 20% lag compared to best practice for energy use and that a significant potential exists for investment in EE/EM activities. These activities include housekeeping measures such as improved lighting, variable-speed motors/drives, and improving power factor; installing co-generation and captive power generation units; and changing manufacturing processes to more efficient and less polluting ones.

Table 1. Energy-efficiency investment potential in India.

Sector	Rupees (millions)	$ (millions)
Aluminum	8,400	190
Cement	3,000	70
Chemicals (caustic soda)	5,000	120
Copper	250	6
Fertilizer	5,000	120
Iron and steel	10,000	240
Pulp and paper	5,000	120
Sugar	3,200	75
Textiles	9,000	200
Zinc	150	3

Potential for investment in each sector varies with the types of options identified in Table 1. These estimates are based on the cost-effective technical potential without taking into consideration the practical challenges or the current industrial stagnation.

The factors that keep energy efficiency low vary among the sectors. A key barrier, however, is the institutional weakness in promoting energy efficiency and better environmental management. Some sectors, such as textiles, have research institutions that provide information on energy efficiency, and the Indian government has established the Energy Management Center and the National Productivity Council to study and promote efficient use of energy. The research and studies, however, have not been fully deployed into energy-efficiency projects.

Financial institutions, such as IDBI, are in a position to help industry overcome some of these key barriers. We recommend that IDBI establish a resource center for this purpose. It would have or be equipped to call upon the necessary technical expertise, collate and maintain data for industry to use, prepare handbooks for each industry sector, and publicize the importance of energy efficiency and environmental management, through the issuance of annual reports and by establishing awards for best practices.

— Jayant Sathaye, Ashok Gadgil, and Manas Mukhopadhyay

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This research is supported by the Industrial Development Bank of India.

Applications Team Report

High-Tech Buildings

For several years EETD staff have researched how to improve energy efficiency in the buildings of high-technology industries—mainly laboratories and cleanrooms, but other energy-intensive facilities as well. Energy usage in high-tech buildings accounts for a larger portion of the operating costs than in other buildings. Energy use is 4 to 100 times more in these buildings. In one 1993 calculation, high-technology buildings in California required approximately 8,800 GWh of electricity to operate. By 1997 the overall electrical energy use of such facilities had grown by 10%. This is a significant increase because it indicates growth even though the trend has been for companies to build these types of facilities outside of California in part because of energy costs. Because these industries change processes and products often, frequent opportunities arise to capture energy savings. Potential reductions of up to 50% have been demonstrated by case studies.

Industries utilizing laboratories and cleanrooms include semiconductor manufacturers and suppliers; pharmaceutical, biotech, and disk drive manufacturing; and a host of others. Some firms have already begun preliminary steps to reduce energy consumption. But firms with fewer resources could benefit from technology transfer and innovative implementation.

Such reasoning led to the development of the *Design Guide for Laboratory-Type Facilities* (see http://Ateam.lbl.gov/DesignGuide/). This web-based, downloadable tool provides valuable information for building designers, owners, and operators. But to foster even larger energy savings, a "Design Intent" tool under development will provide a mechanism to track energy-related information throughout the life cycle of the building.

To approach the challenge of capturing increased energy savings, Applications Team researchers propose to apply research where benefits can be captured from prior research investments. Crucial to this is a long-range roadmap that will give industry clear paths for development, setting performance targets, and overcoming barriers.

Areas for Savings

A number of technologies can be developed to overcome barriers to more energy-efficient cleanrooms. EETD's focus is the facility itself. Improvements in the process systems and equipment in the facility are targeted as later priorities. The vision for savings includes:

- a 50% reduction in building energy use for comparable production within 10 years,
- emissions reductions,
- measurement systems for continuous monitoring and improvement,
- improved facility productivity,
- improved worker and public safety,
- new technologies to reduce cleanroom area and optimize cleanliness,
- improved use of "green" technologies.

Prior Berkeley Lab work with commercial buildings demonstrated that performance-assurance practices need to take into account the largest energy-using components. In most buildings these are the heating, ventilation, and air-conditioning systems. HVAC systems within a research facility present complex challenges because of the large volumes of exhausted and circulated air as well as the need for humidity and filtering. Other areas that could offer additional energy savings include heat-recovery process systems and lighting. EETD staff has conducted research in collaboration with the Northwest Energy Efficiency Alliance, EPRI, and Sematech, and a number of industrial companies interested in energy efficiency.

A low-flow fume hood could be part of an energy-saving strategy for high-tech industries.

Low-Flow Fume Hood

One Berkeley Lab-developed technology that arose from efforts to save energy in high-tech buildings is a low-flow laboratory fume hood. The design provides containment by introducing displacement air flow at the fume hood opening, creating an air dam between the operator and hood contents. The air-dam approach differs from an air curtain in that the air flow is low velocity, supplied from top and bottom, and nonturbulent. The hood helps protect the operator and delivers dramatic cost reductions in construction and operation. Computational fluid dynamic modeling was used to further optimize the performance of the technology. A commercial version of the fume hood is now being developed with an industrial partner.

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This research is sponsored by the U.S. Department of Energy, the California Institute for Energy Efficiency, and the California Energy Commission.

Working Within Markets to Affect Change

Industrial compressed air systems in the U.S. consume nearly 90 billion kWh annually. The efficiency of these systems could be improved by 20 to 50% by applying best practices that rely primarily on changes in operation and maintenance procedures. Yet these best practices are not in common use despite widespread recognition among industry experts. Taking advantage of the large but overlooked opportunities for improving the energy efficiency of entire systems will require a shift in thinking by both system users and the businesses that serve them.

Is there a role for government to work within U.S. industrial markets to encourage greater energy efficiency? EETD's researchers in the Washington, D.C., office think so, and have been developing, testing, and implementing ways to collaborate more effectively with industry in the area of electric motor-driven systems.

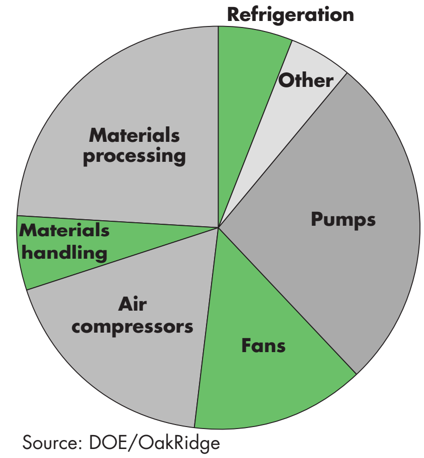
EETD researchers have been seeking methods to effect an institutional and behavioral change, rather than the technological change more typical of energy-efficiency market interventions. It is assumed that the structural shifts resulting from institutional or behavioral change will create an environment for further technological innovation. Since it engages many aspects of a market, this approach is described as collaborative intervention. Its success depends on identifying business opportunities to sustain the desired market change.

Collaborative intervention places government in the role of a broker or facilitator, responsible for setting out initial goals. Market participants are invited to be champions of these goals and collectively determine the best way to achieve these goals. In exchange, government—acting as the broker—can recognize them for the risks they assume. This approach seeks to exploit the different, and potentially complementary, roles and competencies of the public, private, and not-for-profit sectors. The four key elements of this strategy are:

- broadly defining the goals with no predetermined way of achieving them;
- creating an atmosphere of mutual respect;
- acknowledging and accepting that the participants will act in ways that are consistent with their economic and political self-interest; and
- establishing a high tolerance for the ambiguity and tension involved in forming coalitions across typical market structures.

The first application of this approach is the Compressed Air Challenge (CAC), which seeks to transform the customer and supplier relationships for industrial compressed air systems. The CAC is an outgrowth of work on Industry Partnerships for the U.S. Department of Energy's Motor Challenge Program. This industry is suited for a collaborative intervention because of characteristics including market structures, market size, pressure to change, system improvement opportunities, and barriers to achieving those opportunities.

Fourteen project sponsors each contributed $30,000 per year for two years to provide development funds for the project. The sponsors make up an Advisory Board. Another body, the Project Development Committee, represents a cross-section of stakeholders, whether or not they were sponsors. The group decided that its primary mission was education and awareness to encourage a shift from a components to a system services approach. The focus is on encouraging this shift in the relationship between users of compressed air systems and the businesses that serve them.



Motor system energy by application.

Accomplishments to date include:

- in cooperation with the U.S. Department of Energy, prepared, published, and sold more than 1,200 copies of *Improving Compressed Air System Performance: A Sourcebook for Industry*;
- developed and tested a one-day training program for plant engineers, Fundamentals of Compressed Air Systems;
- selected and trained 24 instructors;
- conducted 35 Fundamentals training sessions as of June 1999;
- placed full-page ads in *Plant Engineering* and *Plant Services* magazines and sent a national mailing to 5,000 plant engineers;
- created a web site (http://www.knowpressure.org); and
- began work on a two-day advanced training session.

While the impact of this effort is too new to measure, evidence of change is accumulating. For instance, at one recent meeting of a distributors' association, one seasoned distributor described how the change to a system services approach had built a lasting customer relationship:

"A new customer called me asking for a third bid on a 200 hp air compressor. In the past, I would have sharpened my pencil and submitted the lowest bid possible to try to get a new customer. This time, I asked two questions: 'Are you sure you need one? Do you mind if I come out and take a look at your system to see if you do?' The result was that I didn't sell him a 200 hp compressor; I sold him a smaller one, controls, storage, and other services. I got his system running better than it ever had before. Now that customer thinks I'm a hero."

The collaborative approach is also being applied to the pulp and paper industry, industrial pumping systems, and international work on behalf of the U.S. Department of Energy's Motor Challenge program.

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This work is sponsored by the Office of Industrial Technologies.

Carbon Monoxide Occupational Sensor

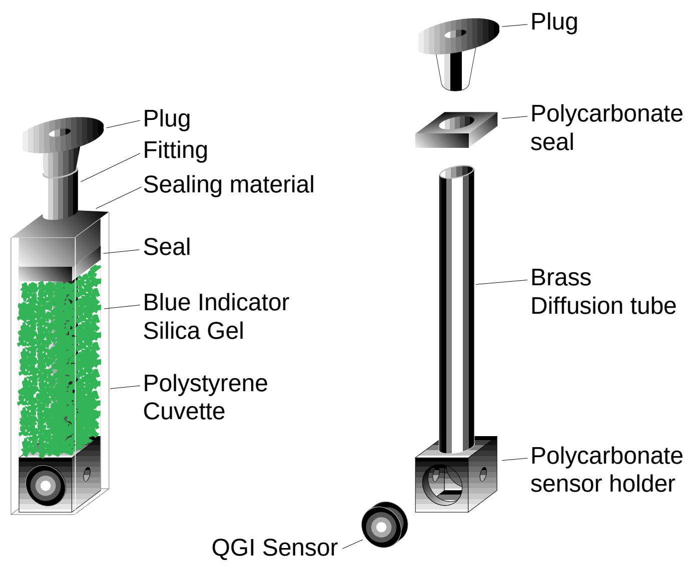
A new lightweight, inexpensive, accurate carbon monoxide (CO) sensor and monitoring system have been developed by EETD researchers and Quantum Group Incorporated (QGI, San Diego). Field testing of the new device at the Moscone Convention Center in San Francisco has shown that it is more accurate than the personal CO monitors currently on the market.

About 19,000 accidental CO poisonings were reported by the American Association of Poison Control Centers in 1995, but very little is known about the actual extent and distribution of CO exposures in the U.S. Five hundred to a thousand accidental deaths a year are attributed to CO poisoning, and it is the number one cause of unintentional poisoning in the U.S. Total numbers of poisonings are difficult to estimate because the effects of sub-acute CO poisoning are easily misdiagnosed as flu-like symptoms such as headaches and dizziness.

Limited Knowledge of Exposures

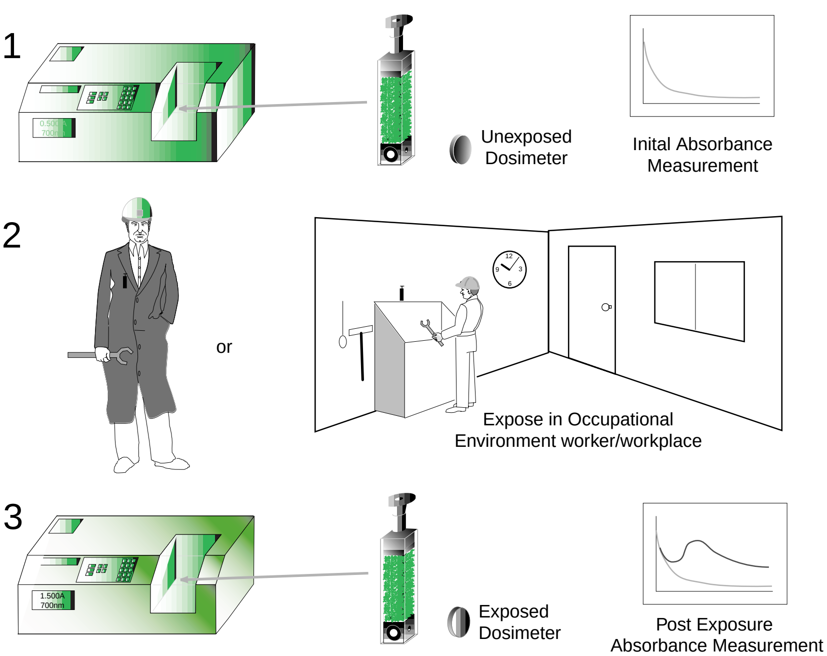
Because there has been no affordable way to accurately measure CO in the field, understanding about CO exposure risks is limited. Some of the current methods of measurement require expensive, heavy equipment or unwieldy air bag samplers. Others are relatively inexpensive and lightweight, but they are not accurate or sensitive enough to provide credible quantitative results for a large number of sites.

To fill this gap in technology, Berkeley Lab and QGI worked together to develop the new CO sensor, which can clip onto a person's clothing. It can be used as an occupational dosimeter, which measures a worker's time-weighted average exposure to CO over an eight-hour period, or as a residential passive sampler measuring time-weighted average exposure in a home or office over a one-week period.



The LBNL/QGI carbon monoxide occupational dosimeter. (NOTE: Silica gel's true color is blue.)

CO poisonings are most often caused by exposure to excessive indoor levels of the gas. Faulty combustion appliances, such as gas stoves or gas-burning water or space heaters, can raise CO levels into the danger zone, as can automobile exhaust in enclosed spaces. Although CO concentrations are regulated outdoors by national and state ambient air quality standards, most people spend 90% or more of their time indoors, which is where elevated CO exposures are likely to occur.



When the user removes the plug, air flows into the diffusion tube at a constant rate (2). The CO in the air reacts with the sensor at the end of the tube, slowly turning it blue. The color change as measured by placing the device into a spectrophotometer, before and after use, indicates the exposure to carbon monoxide (1,3).

How it Works

The LBNL/QGI Occupational CO Dosimeter (LOCD) consists of a square polystyrene vial less than two inches long. The device contains a CO sensor made of palladium and molybdenum, a diffusion tube to control the rate at which CO is sampled, and a cap to seal the system.

When the user removes the cap, CO diffuses to the sensor at a constant rate over the sampling period, typically an eight-hour work shift. CO in the air reacts with the sensor at the end of the tube, turning it from yellow to blue in proportion to CO exposure. Analysis is simple—the device is placed into a standard lab spectrophotometer, which, by measuring its color change, instantly indicates how much CO the sensor absorbed. A single LOCD can be reused many times.

To prove that the sensor works accurately in the field, the EETD research team conducted a study of the CO exposure of workers at San Francisco's Moscone Convention Center in cooperation with Crawford Risk Control Services, an Oakland firm.

continued on page 16

Materials End-Use Efficiency to Reduce Industrial Energy Demand

Most proposed reductions in industrial energy use are reductions in the energy used to produce a constant amount of product, or substitutions of a less energy-intensive material. What are generally absent are "demand-side" or "end-use" approaches that change the way materials are used to reduce the amount that needs to be produced in the first place. As with building energy efficiency, the services delivered are maintained or improved.

The potential for this type of reduction in materials demand has not been explored comprehensively, so is not known. However, reducing materials demand across the board by 20% would reduce industrial energy use by about 20% as well, with tremendous economic and environmental benefits. Many of these benefits are of such a nature that changes in production efficiency do not deliver. In general, end-use efficiency does not conflict with production efficiency; rather it complements it (except for reducing the rate of production facility turnover).

Since end-use efficiency is traditionally not considered an option for materials, little work has been done in the area. However, recent EETD work on paper use illustrates the topic well. Most office workers know from personal experience that the amount of office paper used is considerably larger than necessary to accomplish the tasks at hand, so the notion that paper use can be reduced is readily acceptable.

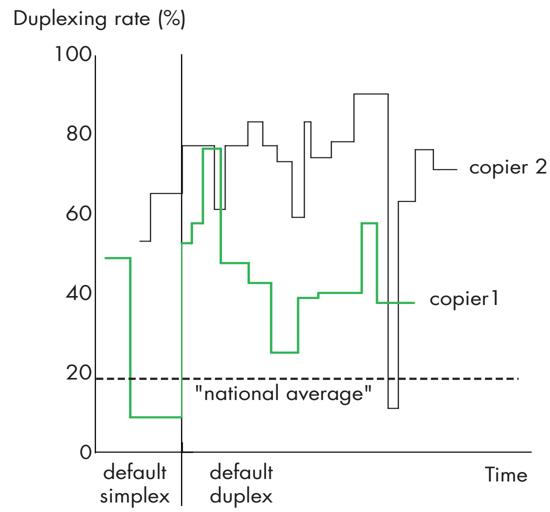
Our work has focused on "copy paper"—the type of paper used in copiers, printers, and fax machines. Most of our effort has documented baseline patterns of paper use, such as measuring the amounts used in different types of devices, activities, and organizations; the costs associated with paper use (particularly imaging); and particular use patterns, such as duplexing rates. We have assessed methods for reducing paper use and their potential, and benefits, and measured the effect of several interventions. Finally, we produced information that others can use to understand and improve their use of copy paper.

A key finding of our work is that while the cost of purchasing copy paper is typically only about $50 per office worker per year, the costs of use are generally about ten times this, or $500. This amount is large enough to make efficiency improvements compelling. We measured duplexing rates on many copiers over extended periods of time. We found that the rates vary widely and that even simple, inexpensive interventions can save considerable paper. In assessing technologies and policies, we have identified several good ways to transform future office equipment to reduce paper use without involving consumers directly. Finally, we provided background research for several "paper efficiency" requirements that were incorporated into the "Copier of the Future," a project of the International Energy Agency.

A Savings Example

An obvious way to use less paper is to use both sides of each sheet. This use is measured by the "duplexing rate," the fraction of images that are on sheets of paper imaged on both sides. For example, three images—two on one sheet and one on another—result in a duplexing rate of 67%. Duplexing rates are usually measured over a period of time for one or more pieces of imaging equipment.

Most copies made today are single-sided. Some documents need to be single-sided or are only one page; others need to be duplexed. However, for many copies, either is acceptable, so shifting some from single-sided to duplexed is a paper-saving opportunity.



The x-axis is the number of images made and so corresponds to time. Each "stairstep" represents about two weeks.

For historical reasons, the majority of copiers have one-to-one copying as the default, but most copiers can be set to default to making double-sided copies.

We measured the duplexing rate on two copiers for several months, and after one month changed the default copy mode to double-sided. For both copiers, the average duplexing rate rose markedly with default duplex. On copier 1, the duplexing rate rose from 38% to 55%; on copier 2, it was already high at 59%, but maintained a 74% average rate. The reduction in paper use in both cases was just over 10%. The "national average" figure of 18% for this size of copier is questionable, but is the best data available.

The figure shows the data in more detail. The x-axis is the number of images made and corresponds to time. Each "stairstep" represents about 2 weeks. The duplexing rate below 20% is almost certainly a data-collection error, as the data point before it is also suspiciously high. The errors cancel each other out when calculating the duplexing rate for the entire period.

Similar results are likely for printers. A 10% reduction in copy paper use nationally would reduce annual paper use by about half a million tons, with a value to the economy in excess of half a billion dollars and energy savings equivalent to 1.6 TWh.

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For further information on reducing copy paper use, see the "Cutting Paper" web site, http://eetd.lbl.gov/paper.

This research is sponsored by the the Department of Energy's Waste Minimization Program and the Environmental Protection Agency's ENERGY STAR® Program.

Research Highlights

An Overview of Proposed ASHRAE Standards

Max Sherman, group leader of EETD's Energy Performance of Buildings Group has written two articles describing the draft ASHRAE Standard 62.2P in the May 1999 editions of the *ASHRAE Journal* and *Contracting Business* (Sherman, M.H. "Standard 62 Goes Residential," *Contracting Business,* May 1999. 56: 5, pp 56-59; Sherman, M.H. "Indoor Air Quality for Residential Buildings," *ASHRAE Journal,* May 1999.) Sherman is the chairman of the ASHRAE Standard Project Committee 62.2P. This standard, "Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings," is now ready for public review. It defines the minimum requirements for mechanical and natural ventilation systems and the building envelope in single-family and low-rise multifamily structures. The intent of the standard is to address public interest in residential indoor air quality and ventilation; that interest has grown with the increase in energy-efficient houses and healthier building materials.

Public review will begin this summer. For more information, contact Max Sherman, (510) 486-4022, or visit the ASHRAE web site (http://www.ashrae.org/ash_home.htm).

XRF Helps Archaeologists Determine the Origin of Ancient Pottery

EETD's Frank Asaro and Robert D. Giauque worked with D. Adan-Bayewitz of Israel's Bar-Ilan University to demonstrate the effectiveness of a new methodology of X-ray fluorescence (XRF) for determining the origin of ancient pottery.

Determining the origin ("provenance") of ancient pottery can help archaeologists better understand the relationships and influences between peoples. Correlating pottery fragments found in excavations with the ancient workshops in which they were made helps illuminate the trade and cultural contacts among ancient settlements.

By measuring the abundances of trace and major elements in a pottery fragment and comparing them with the same parameters in the soil and artifacts at known pottery workshops, researchers can often determine provenance. Instrumental neutron activation analysis (INAA) has been the method of choice for measuring elemental abundances because of its great precision and reliability, but it has some disadvantages. One is that INAA requires a nuclear reactor, and XRF does not. Another involves complicated sample preparation and analytical procedures—INAA results can often take several weeks to complete, even for a small number of samples.

Asaro and Giauque demonstrated that XRF can be used to determine pottery provenance with measurement precision comparable to INAA's. XRF does not require a nuclear facility, relying instead on a widely available lab equipment—a conventional silicon X-ray spectrometer with an X-ray tube. A single investigator can often complete XRF results in just a few hours.

The research team analyzed pottery samples from several ancient Palestinian sites in the Galilee and Golan areas of the Middle East using both the standard INAA method and XRF. The ages of the artifacts ranged from the first century B.C. to fourth century A.D. Adan-Bayewitz, Asaro, and Giauque demonstrated that the 10 most precisely measured by XRF were measured as well as the 10 most precisely measured elements by INAA. XRF was also able to distinguish better than INAA between two sets of pottery from nearby sites that were very similar in composition. The team showed that XRF holds promise as a cheaper, faster method than INAA for determining archaeological provenance while being equally effective.

Adan-Bayewitz, D., F. Asaro, and R.D. Giauque. "Determining Pottery Provenance: Application of a New High-Precision X-Ray Fluorescence Method and Comparison with Instrumental Neutron Activation Analysis," *Archaeometry* 41 (1999), 1-24.

EETD Research Team Wins *Architecture* Research Award

Recognizing the research program "Daylighting with Integrated Envelope and Lighting Systems," *Architecture* magazine bestowed a 1999 Award for Architectural Research on a team of EETD building scientists. The six-year research program demonstrated how to integrate existing and prototype window and lighting technologies into advanced systems that attain greater energy efficiency and occupant comfort than conventional design practice.

The winning team was led by Stephen Selkowitz, head of EETD's Building Technologies Department, and Eleanor Lee, EETD Project Manager. It also included Dennis DiBartolomeo, Francis Rubinstein, Liliana Beltrán, Joseph Klems, Robert Sullivan, Edward Vine, and Robert Clear, all of EETD.

The award, co-sponsored by *Architecture* magazine and the Initiative for Architectural Research, is one of the profession's highest honors for innovative research. The Initiative is a cooperative effort of the Association of Collegiate Schools of Architecture, the American Institute of Architects, and the Architectural Research Centers Consortium.

"This is an excellent example of applied research in which the results are greater than the sum of the individual components because of an integration of scientific knowledge—a real model of what architecture can bring to the table," said Richard Eribes, one of three award jurors. Selkowitz accepted the award for the project team at a ceremony in New York City's Paula Cooper Gallery. The Berkeley Lab research is described in the April 1999 issue of the magazine.

"The honor is yet another recognition of Berkeley Lab's outstanding contributions toward improving our nation's efficient use and conservation of energy," said Laboratory Director Charles Shank. "Stephen Selkowitz and his colleagues are to be congratulated for their creative solutions to the challenges of maximizing the use of natural light in building design."

More information about the award can be found at http://windows.lbl.gov/comm_perf/daylight/.

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During the set-up of shows in the Center's 442,000 square feet of exhibition space, some 40 propane-powered forklifts are active almost continuously throughout the building. Diesel trucks also drive up to interior docks from the outside.

Before the study, Moscone Center management had already put a number of safety measures in place to reduce worker and building occupant exposures to CO, including installing catalytic converters on the forklifts and modifying the building's ventilation system to reduce exhaust concentrations.

The Berkeley Lab team gave the 60 workers who volunteered for the study the new occupational sensor, which was clipped to the workers' lapels. They were also given commercially available diffusion tubes, used to measure CO exposure. The team also measured CO levels using traditional methods, including air bag samples analyzed in an EPA-approved lab procedure and real-time CO personal monitors containing an electrochemical sensor. Exposures were measured over a three-day period.

The tests showed that the LOCD measured average workshift CO exposures accurately to within one part per million. The commercially available diffusion tube underreported CO exposures by an average of about three parts per million. The results show that the new device represents a major improvement over current measurement technology.

Worker CO exposures were almost all below the strict Cal-OSHA occupational standard of 25 parts per million. One worker whose exposure exceeded the standard probably received excessive exposure from operating a forklift in an enclosed semi-truck trailer. QGI is now looking for private-sector partners for distribution and plans to manufacture and market the CO occupational dosimeter.

—Allan Chen and Michael Apte

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"A New Carbon Monoxide Occupational Dosimeter: Results from a Worker Exposure Assessment Survey," by Michael Apte, Katherine Hammond, Lara Gundel, and Daniel Cox, will be published in the *Journal of Exposure Analysis and Environmental Epidemiology.*

This research was sponsored by the Department of Energy under an Office of Science-sponsored Cooperative Research and Development Agreement. An early phase of the research was funded by the Office of Building Technologies, State and Community Programs.

Sources

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