BASIC

BAY AREA SCIENCE AND INNOVATION CONSORTIUM

BASIC Science Futures Report

Innovative Energy Solutions from the San Francisco Bay Area: Fueling a Clean Energy Future

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This report was produced by the Bay Area Science and Innovation Consortium (BASIC), an action-oriented collaboration of the region's major research universities, national laboratories, independent research institutions and research-and-development-driven businesses and organizations.

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Bay Area Science and Innovation Consortium

Advancing the Bay Area's Leadership in Science, Technology and Innovation

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June 2007

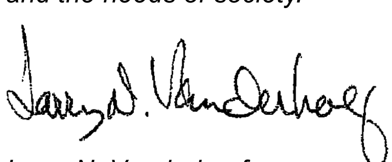
Letter from University of California, Davis Chancellor Larry N. Vanderhoef

The University of California, Davis is proud to be involved with the national effort to address all aspects of research on energy, which has emerged as one of the most compelling issues facing our country and the world. The agenda has been moved forward by our contributions in energy research, including efforts at the Institute for Transportation Studies, the Wind Energy Collaborative, the Biomass Collaborative, the California Technology Lighting Center, and the NEAT (Nanomaterials in the Environment, Agriculture and Technology) organized research unit. We are especially proud of the newly designated California Energy Efficiency Center which will develop and rapidly commercialize products and technologies that will enable us to use less energy in our businesses and homes.

As consumers face higher oil prices and as our federal and state governments continue to seek the best way to provide leadership in developing the energy solutions of the future, Bay Area companies, universities, and research laboratories will be an integral part of these solutions. From the research and development efforts of companies that continue to invest in commercializing and refining alternative energy sources such as solar concentrators and hybrid vehicle engines to the universities and the national laboratories that pursue basic research and provide the building blocks for tomorrow's clean energy solutions like a "green" hydrogen infrastructure and green algae-powered photovoltaic cells, Bay Area institutions will continue to pursue energy research that has the potential to fundamentally change the assumptions underpinning our current energy practices.

While these efforts, and the efforts of our fellow Bay Area researchers, will bring us closer to sustainable energy solutions, we must continue to work together, building upon our research specialties, pursuing strategic partnerships between corporations and academia, and working with the knowledge that the solutions to our energy needs have the potential to change our daily lives and how we relate to the rest of the globe.

The University of California, Davis, other BASIC members, and other Bay Area institutions and companies are quickly pursuing the needed solutions to energy issues. I am confident that our region will continue to be a source of innovative technology and policy that will address our current and future energy needs while also safeguarding the environment and the needs of society.



Larry N. Vanderhoef
Chancellor
University of California, Davis

Letter from Lockheed Martin Advanced Technology Center Vice President James T. Ryder

Since the beginning of the 1960s, Lockheed Martin has been developing and deploying renewable energy technologies, including the first nuclear reactor in space, the first fuel cell power system for the Navy's Deep Sea Rescue Vehicle and the largest space solar arrays for NASA's Space Station Freedom. We are continuing to develop renewable energy and in-situ resource utilization technologies for the planned manned Lunar and Mars missions which will allow man to flourish in the harshest of environments. With this heritage and current focus we are committed to work with the Bay Area scientific community to make significant progress in developing new technologies which will markedly improve life on earth with the minimum of environmental degradation and maximum effective use of resources.

Lockheed Martin's Advanced Technology Center, established in Palo Alto in the 1950s, will take the lead for the Corporation in this endeavor. We have mustered the experienced personnel who will work with other BASIC enterprises to further the goals of the consortium for the prosperity and health of California and the United States.

James T. Ryder
Vice President, Advanced Technology Center
Lockheed Martin Space Systems Company

Letter from Lawrence Berkeley National Laboratory Director Steven Chu

We live in a truly magical time in which, with the flick of a finger, the power of 10 horses flows out of a wire in our homes to clean our carpets. We go to the local market under the pull of hundreds of horses and fly across our continent with 100,000 horses. We have the technology and the economic possibility to elevate the living conditions of much of humanity to heights well beyond the dreams of Roman emperors. What has made all this possible is our ability to exploit abundant sources of energy. The worldwide consumption of energy has nearly doubled between 1970 and 2001; by 2025, it is expected to triple. The extraction of oil, our most precious energy source, is predicted to peak sometime within 5 to 30 years, and most of it will be gone by the end of this century.

As a result, among America's most serious concerns are national security (intimately tied to our energy security), long-term economic competitiveness and the dangers of global warming. I believe that energy is at the center of all of these concerns, and thus is the single most important problem that science and technology must solve in the coming decades. Unfortunately, there appear to be no magic bullets to solve the energy problem. While efficiencies play a huge role in defining how much energy we consume, we must also create a diversified portfolio of investments to develop sustainable, CO_2*-neutral energy sources.*

As the director of Lawrence Berkeley National Laboratory, I am a part of the cluster of research institutions, universities, and companies in the Bay Area that are taking a leadership role in finding the solutions to our continued need for energy. The energy challenge is beginning to capture the imagination of the nation's very best scientists, and the Bay Area's intellectual and economic vitality will provide them with the test-bed and the support for mounting a major, multidisciplinary initiative to create sustainable sources of energy while maximizing the efficiency of our current usage.

My hope is that BASIC members and other Bay Area institutions and companies can combine some of the most rapidly advancing areas in science, such as nanotechnology and synthetic biology, to create new technologies that can transform the way we produce energy through nuclear fusion, wind generation, and especially the conversion of solar energy into chemical energy that can be tapped on demand.

Bay Area institutions such as the Lawrence Berkeley National Laboratory are designing new initiatives to develop sustainable, CO_2*-neutral sources of energy that will draw upon many of our core strengths. With their strengths in physics, biology, chemistry, computational sciences, materials science, and engineering, our institutions are uniquely positioned to tackle this challenge. We have world-class facilities, experienced researchers and entrepreneurs, and decades of experience at the forefront of energy-related research and development. The Bay Area is collectively an incredible scientific resource.*

I am confident that any solution to our continued and ever-growing need for energy will involve Bay Area institutions and companies as we continue to forge ahead in a nation-wide quest to secure our energy future.

Steven Chu
Director
Lawrence Berkeley National Laboratory

Letter from BASIC Chairman Regis B. Kelly

It is with great pride that the Bay Area Science and Innovation Consortium presents this report on alternative energy technologies—the second in a series of BASIC "science futures" reports.

The Bay Area is quickly developing an impressive international reputation in alternative technologies, as demonstrated by the $500 million recently given to create the Energy Biosciences Institute (EBI) at Berkeley on top of the $225 million committed to Stanford for its Global Climate and Energy Project. The Bay Area is thus poised to take the lead in the development of alternative energy technologies, just as it did for information technology and biotechnology.

Never has the United States had a greater awareness than it has now of the dangers of continued reliance on fossil-fuel energy. There is nonpartisan support for alternative energy sources that are technologically feasible and cost-effective. It is essential, however, that this support be driven by knowledge, not just opinion. We are proud of BASIC's energy report because it is a compendium of useful information across the whole spectrum of energy-related activities in the Bay Area. All of us, no matter what our background in energy technologies, will find something exciting and new in these pages. It could be the magnetic train that levitates at walking speed, the mobile nuclear reactor that does not need attention for two decades, the new propeller designs for wind generators, the generation of energy from restaurant kitchen grease or the batteries that can survive 500,000 charge/discharge cycles. Reading this report gives us a satisfyingly broad view of the complete gamut of alternative energy activities in the Bay Area, a view of great value to those who must make decisions at research, urban planning, economic and even personal levels.

There are no easy, inexpensive answers, but, as this report from BASIC shows, rapid progress is being made and, with the new sense of political urgency at all levels of government, we can now have hope that the answers will come in time.

Regis B. Kelly

Regis B. Kelly
Chairman, Bay Area Science and Innovation Consortium
Executive Director, QB3
California Institute for Quantitative Biomedical Research
University of California

Foreword

The world's supply of fossil fuels is being depleted at an ever-increasing rate and there will be no replenishment. In barely 200 years, the human race has consumed a substantial portion of the fossil fuels that were built up over hundreds of millions of years. The leading R&D institutes in the San Francisco Bay Area, including members of the Bay Area Science and Innovation Consortium (BASIC), are working to develop a broad range of alternative energy technologies that are renewable and carbon-neutral—meaning the sources can be replenished and their use does not contribute to atmospheric global warming effects. These alternative technologies fall under the general categories of biomass fuel, electro-chemical and magnetic technologies, geothermal energy, hydrogen fuel, solar, wind and nuclear energy. Bay Area researchers are also investigating an extensive variety of strategies for improving the efficiencies of the fossil fuel energy technologies in use today. The ultimate goal is to provide an overall energy portfolio that is viable, sustainable and environmentally supportable.

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Introduction

The economies of the United States and all the other industrial powers in the world today are built upon the burning of fossil fuels—primarily oil—for energy. Someday the world will run out of fossil fuels. That's a fact no one can dispute. Arguments arise as to when this event will occur and what to do about it in the meantime. Those who think the problem is a long way off should heed the cautionary tale of Marion King Hubbert. In 1956, Hubbert was a geophysicist working for the Shell Oil Company. Against the wishes of his employer, he made public his calculations which predicted that the rate at which oil could be extracted from the lower 48 states would peak around 1970 and begin a rapid decline. Hubbert presented his model at a time when the lower United States was seemingly afloat atop an ocean of oil. Consequently, he became a figure of ridicule in the oil industry, a laughing stock prophet of doom. When his model turned out to be astonishingly accurate, everyone in the energy industry stopped laughing. Applying Hubbert's model to the global oil situation today produces sobering results. The deadline for finding alternatives to oil will arrive far sooner than most of us imagine. What many who publicly deny the urgency of the problem fail to take into account is that the crisis does not occur after the last drop of oil is pumped from the ground, but when the rate at which oil can be pumped out of the ground starts to diminish. Depending on how optimistic or pessimistic the input numbers, Hubbert's model predicts that this event will transpire within the next 10 to 30 years.

The worldwide consumption of energy has nearly doubled between 1970 and 2001, and is expected to triple by 2025. The United States alone accounts for one-quarter of the world's total energy consumption, and more than three-quarters of this is supplied by fossil fuels. The growing economies of countries such as China and India guarantee that future demands for energy will not only rise, but will escalate at increasingly faster rates. Even the most stringent conservation measures will only prolong the inevitability that the world's dependency on the burning of oil and other fossil fuels is not sustainable over the long term. The consensus among the leading authorities is that we are not going to be able to drill or mine our way out of this pending crisis.

A growing number of energy experts believe that the global economy is nearing the peak of its ability to produce relatively cheap oil through conventional means. Shifting the burden of energy production to other more abundant sources of fossil energy such as coal can greatly extend the period on which we can rely on fossil sources, but eventually that too will run out. In the meantime, the continued large-scale use of fossil fuels—barring the development of new clean-burning technologies—is likely to fundamentally compromise the planet's atmosphere through CO_2 and other emissions that lead to global warming. Steven Chu, Nobel Laureate, director of the Lawrence Berkeley National Laboratory and a leading advocate for developing alternative energy sources observes: “The good news is that we have enough coal to last another 200 years and perhaps even 1,000 years. That’s also the bad news because coal puts out even more global warming emissions than oil.”

Chu is referring to the double edge of the fossil fuels sword. Not only are fossil fuel supplies finite and nonrenewable, but their continued burning will increase the emission of greenhouse gases, primarily carbon dioxide, that contribute to global warming. There is no longer any serious scientific debate on the reality of global warming. It is the overwhelming consensus of the global community that the earth is warming and that the emission of greenhouse gases such as carbon dioxide through the burning of fossil fuels is a significant factor. Climate models consistently project that over the next 30 years, the burning of fossil fuels will add three times as much carbon dioxide to the atmosphere as we have added over the past 250 years. From melting ice caps and rising sea levels to crop failures, the future under the continued mass consumption of fossil fuels looks untenable. Therefore, if the long term energy needs of this nation and the world are to be met in an affordable, sustainable, and environmentally responsible way, alternatives to fossil fuels must be developed.

With the declaration by President George W. Bush in his 2006 state of the nation address that “America is addicted to oil,” the federal government began to address more aggressively the need for national initiatives and funding in alternative energy research. The Committee on Prospering in the Global Economy of the 21st Century, sponsored by the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine, called for the establishment of ARPA–E (Advanced Research Projects Agency–Energy). Modeled after the popular Defense Advanced Research Projects Agency (DARPA) which gave birth to the Internet, this new federal agency will eventually be funded at $1 billion annually in order to jump-start and support energy research and development throughout the United States. In addition, President Bush announced the Advanced Energy Initiative, which would increase funding for clean energy research by 22 percent at the U.S. Department of Energy (DOE) in order to push for breakthroughs in alternative energy sources, including biofuels, solar, wind and nuclear.

At the state level, California leads the nation in setting progressive energy policies, with an emphasis on renewable energy sources backed by state government mandates, policy goals, research funding and market incentives. At $2.9 billion, the California Solar Initiative sponsored by the California Public Utilities Commission (CPUC) is the largest solar incentive program in the nation. Launched by Governor Schwarzenegger as the Million Solar Roofs Initiative, the program rewards consumers who install solar energy systems and makes solar power a standard option in new housing subdivisions. This initiative is expected to produce 3,000 megawatts of electric power—or the equivalent of five modern generating plants.

The CPUC has also launched the nation’s most aggressive energy efficiency campaign, allowing California utilities to invest more than $2 billion in energy efficiency programs. The state has set aggressive energy targets, aiming for government and private commercial buildings to reduce their electricity consumption by 10 percent per square foot by 2010, and 20 percent by 2015. In the field of electricity procurement, California utilities are now required to acquire 20 percent of their electricity from renewable sources by 2010 and 33 percent by 2020.

Transportation fuels account for 40 percent of greenhouse gas emissions in the state. To address this problem, the Hydrogen Highway Initiative, with over $12 million in initial state support, aims to establish hydrogen fueling stations from one end of the state to the other, eventually linking the Mexican border with British Columbia. In January 2007, California also created the world's first carbon standard for transportation fuels, requiring that the carbon intensity of transportation fuels sold in California be reduced at least 10 percent by 2020. Perhaps most aggressively, the California Global Warming Solutions Act (Assembly Bill 32), signed by the Governor in September 2006, establishes the nation's first statewide limit on greenhouse gas emissions, with the goal of reducing emissions in California to 1990 levels by 2020—or 25 percent below forecasted levels.

In embracing clean energy and global warming targets, California has seized a position of national leadership. In the western states, Governor Schwarzenegger led the Western Governors' Association in adopting clean energy goals that will bring 30,000 megawatts of clean energy online by 2015 and increase energy efficiency by 20 percent by 2020. Increasingly, California's leadership is extending nationally as well.

Funding obtained through such initiatives will strengthen the already sizable alternative energy research and development efforts under way at a cluster of federal laboratories, universities, corporations, and startup companies in the San Francisco Bay Area. This cluster of R&D expertise includes the University of California at Berkeley and Davis, Stanford University, the Lawrence Berkeley National Laboratory (Berkeley Lab), the Lawrence Livermore National Laboratory (LLNL), Sandia National Laboratories (SNL), and Bay Area corporations such as Chevron, Lockheed Martin, Palo Alto Research Center, Inc. (PARC), Pacific Gas and Electric Company (PG&E) and the Sacramento Municipal Utility District (SMUD). There is also an emerging vanguard of entrepreneurial Bay Area startup companies that are able and eager to commercialize the research coming from the universities and national laboratories. Together, this assembly of public and private scientific, engineering and entrepreneurial expertise is positioned to make the San Francisco Bay Area the national and global leader in alternative energy R&D.

To engage policymakers, the general public and potential investors, representatives of the Bay Area's top research facilities have organized the Bay Area Science and Innovation Consortium (BASIC). Through BASIC, they are sponsoring this report on where Bay Area alternative energy technologies research stands today, where it is headed tomorrow, and what challenges lie ahead for a viable, sustainable and renewable energy strategy.

Glossary of Frequently Used Abbreviations

Berkeley Lab = Lawrence Berkeley National Laboratory

DOE = U.S. Department of Energy

LLNL = Lawrence Livermore National Laboratory

PARC = Palo Alto Research Center, Inc.

PG&E = Pacific Gas and Electric Company

UC = University of California

SNL = Sandia National Laboratories

BIOMASS FUEL

BIOMASS FUEL

Biomass
Image courtesy of the Lawrence Berkeley National Laboratory

Biomass is plant matter such as trees, grasses, agricultural crops or other biological material that can be used as a solid fuel, or converted into liquid or gaseous forms for the production of energy. Biomass as an energy source has the distinct advantages of being both plentiful and renewable.

"We know that biomass is a net energy winner; with investment and innovation, it could be a huge resource," Dan Kammen, co-director of the Berkeley Institute of the Environment and founding director of the Renewable and Appropriate Energy Laboratory (RAEL) at UC Berkeley has said. "In the past, the United States has been an energy hunter-gatherer, but in the future we need to become energy farmers."

Extracting energy from biomass, however, poses several challenges. Whereas all biomass can be easily combusted to generate heat that can be used to run gas/steam turbines to produce electricity, most biomass combustion processes are inefficient and environmentally harmful. The main pollutants from direct biomass combustion are tars, particulates, and volatile organic compounds (VOCs). To produce energy that is environmentally benign and carbon-neutral, biomass must be converted into a liquid or gaseous form.

A well-established technology is the fermentation of starches and sugars to produce ethanol, which can be added to gasoline or used directly as an engine fuel. Although this technology is mature and being practiced in the U.S. Corn Belt, research is being conducted at Stanford to increase the amount of energy captured by plants and to improve the efficiency of the fermentation process. While some Stanford researchers are modifying plant cells through genetic engineering to increase cellulose production, others are developing novel yeast strains, which may be able to ferment cellulose and lignin, the hard, fibrous content of plants, obtained from wild grasses and agricultural or forestry waste products. Although neither cellulose nor lignin can be directly fermented into ethanol using current technologies, there are alternative technologies that have been proposed whereby these biomass products would either be first converted into precursors and then fermented into ethanol or some other liquid fuel, or else gasified with the use of air/oxygen and steam to produce syngas, a mixture of hydrogen and carbon monoxide that can be converted into a liquid fuel. Syngas can also be reformed to produce hydrogen for fuel cells.

Biomass, or plant vegetation, for use as a source of energy, offers the distinct advantages of being both plentiful and renewable. The use of biomass is especially promising for the production of carbon-neutral transportation fuels to replace gasoline.

Another renewable energy source from an agriculture product is biodiesel fuel. Biodiesels can be made from oils obtained from plants/crops such as soybeans, peanuts and cotton. The oils from these sources are mainly triglycerides of fatty acids and not directly suitable as diesel substitutes. Transesterification processes convert the triglycerides into simple esters of the corresponding fatty acids (for example, Fatty Acid Methyl Ester or FAME), which can be direct substitutes for diesel fuels.

In addition to agriculture and forestry products, a third significant source for biomass is municipal waste. The biomass component of municipal waste consists mainly of cellulose (from paper products and yard waste) and lignin (from yard waste). This waste can be combusted or gasified into syngas. Already, a number of Bay Area companies have implemented projects that convert municipal and industrial biomass waste into electricity.

BASIC member institutes are going after new biomass solutions from a variety of different approaches.

UC Davis is the home of the California Biomass Collaborative, which has as its mission the sustainable management and development of biomass in California. The Collaborative administers a comprehensive statewide collaborative program in scientific research and innovation, technology development, demonstration and deployment, and education and training, to support and integrate efforts of the State in advancing efficient, safe, reliable, affordable, and environmentally sound biomass systems. In partnership with the California Energy Commission and the extensive base of agricultural research at UC Davis, the Collaborative provides stakeholders and interested parties a forum in which to discuss major issues and to set up statewide coordination of biomass research, policy, and communication activities. The Collaborative includes representatives from the California biomass industry, state and local government agencies, the environmental community, the University of California, federal agencies and national laboratories, and other related academic and public organizations.

One of the biomass projects currently implemented and managed by the Collaborative is a statewide biomass inventory, which has been compiled into spreadsheet and geographic information system (GIS) database formats aggregated by biomass resource type at the county level. From the resource assessments, estimates were made of current biomass gross and technical electrical generation potential. Projections to 2017 have also been made for the purposes of evaluating potential contributions biomass can make to California's Renewable Portfolio Standard (RPS). The GIS resource database is accessible to the public in a web-based Biomass Facilities Reporting System, which includes performance information on biomass facilities throughout the state and provides a perspective on the current and planned status of the industry.

Also at UC Davis, is the California Institute for Agricultural Research (CIFAR), which has among its goals the production of low-cost carbohydrates from California biomass (rice straw, mixed wood waste, yard waste, orchard trimmings). CIFAR has developed microbial and enzyme systems for tailoring the conversion of rice straw to products, including mixed carbohydrates, lactic acid, ethyl lactate and ethanol. In addition, CIFAR works with the U.S.

Department of Energy (DOE) and its National Renewable Energy Laboratory, the Pacific Northwest National Laboratory, the Argonne National Laboratory, and the California Energy Commission.

Berkeley Lab has established the world's first Synthetic Biology Department, which seeks to understand and design biological systems and their components to address a host of problems that cannot be solved using naturally occurring systems. One of the projects being planned is an attempt to synthesize, through genetic engineering, the microorganisms from the guts of termites, cows and certain other animals, or those found at the bottom of swamps, that are able to convert cellulose and lignin into precursors that can be used to produce ethanol and other liquid fuels. This method of biofuel production is called "cellulosic technology."

While fibrous plants such as switchgrass and willow trees are ideally suited for cellulosic technology, even farm waste could be used. According to some estimates, there are a billion tons of currently unused waste available for ethanol production in the United States. Development of cellulosic technology is included in Berkeley Lab's Helios Project initiative, which is a multidisciplinary research effort designed to accelerate the development of renewable and sustainable sources of energy using sunlight. As part of their effort to advance cellulosic technology, synthetic biologists at Berkeley Lab, working closely with UC Berkeley researchers seek to: 1) engineer organisms to produce fertilizers on-site—especially photosynthetic nitrogen fixation in the form of ammonia—to avoid the large fossil fuel consumption by conventional manufacturing processes and fertilizer transportation; 2) engineer novel metabolic pathways for the conversion of cellulose and lignin to fuel (ethanol, methanol, methane, hydrogen); 3) engineer green algae and cyanobacteria with improved photosynthesis rates; and 4) engineer biologically-inspired synthetic catalysts for key bond forming and breaking steps for fuel formation and interconversion of various forms of fuels.

To increase production, researchers at SNL have started a three-year project to develop enzymes that are more stable during the pretreatment steps involved in the initial breakdown of cellulose and lignin materials. This project combines computational modeling and genetic engineering to produce these enzymes using rational design principles.

Chevron Corporation has announced it will provide $25 million of funding for biofuel research projects at UC Davis over five years. By building upon UC Davis' strong programs in converting food-processing wastes and agricultural biomass to energy, Chevron will address the issues that need to be resolved—from genetics to thermochemical reactions to economic forces—in order for biofuels to be used effectively as a transportation fuel.

Based on a recent UC Berkeley study of ethanol in the United States, Alex Farrell, an assistant professor of energy and resources and one of the study's co-authors, said, "Ethanol can be—if it's made the right way with cellulosic technology—a really good fuel for the United States."

Added Kammen, another co-author of the study, "Substituting cellulosic ethanol for gasoline can slash greenhouse gas emissions by 90 percent or more."

The other promising approach to converting cellulose and lignin to a useable fuel is biomass gasification, followed by physical and chemical processing of the resulting syngas, either to make cleaner burning gaseous or liquid fuels or to make electricity through the use of fuel cells. The four key technologies necessary for this approach to be viable are biogasification, gas clean up, shift reaction, and final synthesis. Of these, the last two have been amply demonstrated in the commercial sector. For example, Sasol, a South African energy company, has been using these technologies for decades to produce liquid fuels from coal. The first two have been demonstrated on a commercial scale for coal, but not yet for biomass.

Researchers at BASIC member LLNL, in collaboration with the University of Washington, the National Renewable Energy Laboratory (NREL) and IdaTech, are exploring the possibility of biogasification of biomass by means of a mobile methanol generator. A mobile unit could be taken to the source of the biomass, where it would convert the biomass to methanol. Once the biomass resource at a given place is depleted, the unit would move to the next location. Although biomass is a distributed resource with low energy density, thus making large scale transportation uneconomical, the mobile unit may serve a niche in some areas of the country, such as remote localities away from the power grid.

Biomass as a source of renewable and carbon-neutral energy is about far more than just the production of ethanol or other liquid fuels. For example, one Bay Area institution is already using biomass in the production of electricity. The Tracy Biomass Plant has been operating since 1990. At the present time, all of the fuel used at the plant is processed offsite by independent wood processing companies and delivered to the plant in clean form, such as chips. Slightly less than half the fuel is from agricultural sources and the remainder comes from East Bay urban waste wood.

Another Bay Area company, Chevron Energy Solutions (CES), a subsidiary of Chevron Corporation, has helped the City of Millbrae to implement an innovative biomass project. In 2005, Millbrae and CES began construction of facilities at the Water Pollution Control Plant (WPCP) that will generate on-site electricity from restaurant kitchen grease and other organic matter. The upgrades to the WPCP will make it one of the first wastewater treatment plants in the U.S. to receive and process inedible grease in a comprehensive system specifically designed to control odors, generate reliable power, reduce energy costs and provide a new municipal revenue stream.

The new WPCP system will efficiently create and use a free biofuel—digester gas produced from grease—and will increase by 40 percent the amount of "green power" now generated by the facility's cogeneration plant. Because the system will generate electricity on site, the City will avoid having to purchase about 1.5 million kilowatt-hours from the local utility each year.

The innovative new system is a culmination of nine months of collaborative planning by the City of Millbrae and CES. The upgrades provide a novel solution to reduce the burden on landfills, support the city's energy needs, renovate the city's aging wastewater treatment infrastructure, and simultaneously recoup costs. The system's equipment will be enclosed to minimize odors and will include: 1) a new 250-kilowatt microturbine cogeneration system, fueled by natural and digester gas, to power the WPCP's wastewater treatment facilities; 2) a compressed natural gas tank to store fuel on the site of an innovative facility that will receive inedible kitchen grease produced mostly by local restaurants and collected by hauling companies; 3) chopper pumps that reduce grease particle size; and 4) anaerobic digester tanks which house microbes that digest organic matter from wastewater and produce methane (natural gas) as a byproduct that can be used to fuel the microturbine. The goal is to provide a revenue stream for the City and a source of methane for on-site power generation.

The WPCP facility will be easily accessible, operate 24 hours a day, and provide deodorizing washes for grease hauling trucks. Excess heat produced by the microturbine will warm the digester tanks to their optimum temperature. This beneficial use of otherwise wasted energy while generating electricity is known as "cogeneration."

Even though combustion of biomass is already practiced, researchers are actively looking for fundamental ways to overcome some of the difficulties associated with this technology. One investigation, sponsored by the Global Climate and Energy Project (GCEP) at Stanford University, is characterizing the fundamental chemical and physical processes that control the conversion of coal char and biomass char to gaseous species in the type of environment most likely to be established in advanced gasifiers, boilers and furnaces. Design of boilers, burners and gasifiers requires an understanding of the processes that control the physical transformations that fuel particles undergo when exposed to hot, oxidizing environments. It also requires an understanding of the chemical reactions responsible for conversion of the solid materials to gaseous species and ash. GCEP researchers are developing fundamentals-based submodels for calculating particle mass loss, size, apparent density and specific surface area evolution during char conversion.

The Direct Carbon Conversion fuel cell being developed at LLNL is another promising new combustion technology that is aimed at making more efficient use of biomass-derived carbon. The key to this project is to feed the chars derived from coal or biomass to a fuel cell containing a molten carbonate matrix in which the carbon is oxidized electrochemically to generate electricity. Electrochemical oxidation of carbon is inherently more efficient than that of hydrogen because of technical thermodynamic considerations. Analysis shows that, at least in theory, it is possible to obtain 100 percent conversion efficiency in a carbon fuel cell.

Even though the technology of synthesizing chemicals into liquid fuels is mature, improved fundamental understanding is likely to lead to process improvements. Researchers at Berkeley Lab and UC Berkeley are developing novel catalysts for the synthesis of fuels from syngas and carbon dioxide. The present program is focused on the strategic design of novel catalysts of potential interest for the production of fuels and chemicals in an energy efficient and environmentally acceptable fashion. Of particular interest are the conversion of alkanes to alkenes and functionalized products, and the synthesis of fuels and chemicals from carbon monoxide and carbon dioxide. To achieve these goals, a molecular understanding of catalytically active centers is used together with knowledge of how to synthesize unusual chemical and physical environments at such centers. The program involves a synergistic combination of efforts in the areas of catalyst synthesis, characterization and evaluation. Quantum chemical simulations of catalytically active centers help guide the interpretation of experimental findings and suggest novel structures to be attempted synthetically.

Biomass is expected to have its greatest impact as a source of energy used for transportation purposes, which account for approximately one-third of the nation's total energy consumption. As Berkeley Lab director Steven Chu has said, "With sufficient conversion efficiency, we could replace gasoline with fuels based on biomass to meet all our transportation energy needs using only about 25 percent of our arable land, most of which farmers are being paid not to grow crops on."

Chu's prediction refers to the long-term development of cellulosic and other proposed technologies. However, even today, biofuel production can be an important part of an efficient and robust near-term National Energy Policy. Already biofuels are being used in the form of blended U.S. transportation fuels. It has been estimated that in the near- to mid-term, biofuels with modest improvements could displace up to 30 percent of the petroleum fuels currently consumed in the transportation sector. The realization of a cost-efficient biorefinery pipeline that produces energy through multiple renewable processes is envisioned to strategically benefit the overall national energy balance.

Numerous existing biofuel production techniques utilize carbon dioxide (CO_2) as their carbon source, and thus the conversion of feedstocks into fuel can help mitigate or stabilize CO_2 emissions by establishing a zero, or, for some projections that include carbon sequestration, even a slightly negative carbon balance lifecycle. Because of the growing concerns for pollution, emission controls and/or fuel blends that contain set levels of biofuels (i.e., bioethanol, biodiesel) are now mandated in many local regions across the nation, and 39 states, including California, have enacted incentive programs for biomass/biofuel production and utilization. The Energy Policy Act of 2005 also mandates an increase in the amount of biofuel (primarily ethanol) that must be mixed with gasoline sold in the United States to triple the current requirement (7.5 billion gallons by 2012). With this precedent, as well as recent developments in the realm of biofuels, bioethanol is the clear priority for near-term biofuel production in the United States.

Several BASIC research institutions, companies, and universities are actively studying ways to improve current biofuel and bioethanol production technologies. For example, Chevron Corporation has formed a biofuels business unit to advance technology and pursue commercial opportunities related to the production and distribution of ethanol and biodiesel in the United States. The company is identifying areas where it can leverage production experience and improve the quality and efficiency of first generation biofuels such as ethanol and biodiesel. In addition, Chevron is developing next-generation production technology to produce fuels from waste products and energy crops. Chevron Technology Ventures, a division of Chevron USA, is participating in an E85 demonstration project with the State of California, General Motors and Pacific Ethanol. Over a one-year period, the project will study the performance, efficiency and environmental issues related to the use of California-formulated E85, a renewable fuel comprising 85 percent ethanol and 15 percent gasoline.

At UC Davis, researchers with the NEAT (Nanomaterials in the Environment, Agriculture, and Technology) program are investigating the tolerance to ethanol and higher alcohols of the yeasts and other organisms that degrade a variety of sugars directly. This is one of the key issues in increasing the productivity and profitability of biorefinery-based production. Even though organisms such as yeast have the capability of withstanding ethanol concentrations up to 15 percent, ethanol tolerance in yeasts and other organisms is often much lower and depends upon processing conditions. The toxicity of the higher alcohols, such as butanol, to these fermenting organisms is even greater. Researchers at NEAT are studying the effects of cell membrane composition on the alcohol tolerance of yeast and other microorganisms. A better understanding of alcohol tolerance and the effects of lipid bilayer composition on resistance should allow a rational approach to improving biorefinery production strains. This, in turn, could result in an increase in the final end concentrations of alcohols, which would significantly lower the cost of biofuel production.

Another significant Bay Area resource actively researching biofuels is the DOE-funded Joint Genome Institute (JGI). Located in Walnut Creek, JGI was created in 1997 to unite the expertise and resources in genome mapping, DNA sequencing, technology development, and information sciences pioneered at the DOE genome centers at Berkeley Lab, LLNL and Los Alamos National Laboratory (LANL). Over the past three years, JGI has established a sequencing program on biological targets that factor prominently in the DOE's clean energy and carbon management missions. These include sequencing the genomes of dozens of microbes, including those that convert ethanol more efficiently and can tolerate higher levels of ethanol, and those involved in degrading recalcitrant biopolymers such as crystalline cellulose. Most recently, JGI led an international effort to decode the first tree, the ubiquitous and robust poplar, which is potentially a vast source of biofuel feedstock for numerous conversion technologies. Another target of JGI's bioenergy efforts is the development of genetic information on microbes located in termites, which are capable of producing two liters of hydrogen from fermenting one sheet of paper. Termites accomplish this by exploiting the metabolic capabilities of about 200 microbes that are known to inhabit their hindguts. JGI researchers have conducted bioprospecting of these termites in the jungles of

Costa Rica. Through the emerging strategy of metagenomics: isolating, sequencing, and characterizing DNA extracted directly from the actual habitat in which they live, it is hoped that future breakthroughs can be realized near-term.

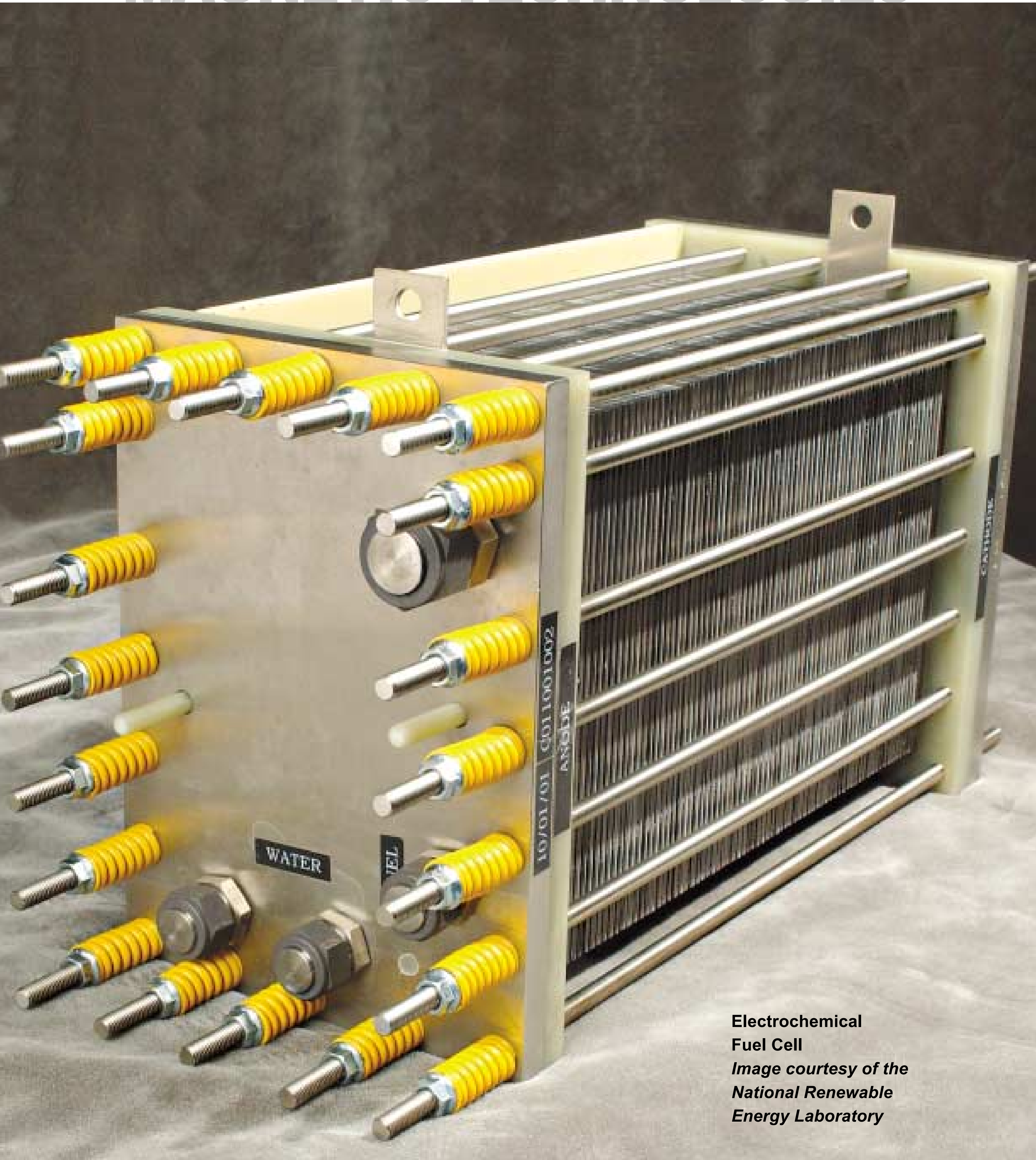
There are also several groups within BASIC member institutes that are actively developing the tools necessary to evaluate the economic feasibility of biofuels. A thorough and robust understanding of the process economics and energy balance analysis of these biofuel systems is absolutely essential if they are to become self-sustaining and profitable. UC Berkeley's Energy and Resources Group conducts programs of graduate teaching and research that treat issues of energy, resources, development, human and biological diversity, environmental justice, governance, global climate change and new approaches to thinking about economics and consumption.

In addition to the biology-focused pathways to liquid biofuel production, there are also thermochemical pathways for converting biomass sources of almost every type into useful liquid fuels for transportation use or local power production (distributed energy). These fuels are viewed as potential transportation fuel substitutes in the longer term (2025) and include synthetic liquid transportation fuels such as diesel, methanol, dimethyl ether, and hydrogen. These fuels can be produced from biomass using thermochemical conversion technologies developed for gas-to-liquids (GTL) processes (i.e., Fischer-Tropsch). These biomass-to-liquids (BTL) fuels are dense in hydrogen and are virtually sulfur free. As such, they are cleaner, more efficient and offer several advantages for applications such as fuel cells. Europe is already beginning to invest in this technology development through several commercial and government programs.

Pyrolysis oils have several properties that produce difficulties in storage, handling, and combustion. These properties relate to the content of suspended solids (char particles), acidity, water content, and viscosity. The thermochemical path that has been most extensively investigated for liquid biofuel production from distributed biomass sources is fast, or "flash" pyrolysis. In this technique, a milled solid biomass is rapidly heated to a moderately high temperature, liberating most of the biomass as heavy vapor species that are subsequently cooled and condensed into a liquid fuel known as biomass pyrolysis oil, or more simply bio-oil or bio-crude. With adequate high-temperature filtering of fine char particles so that they do not enter the condensed liquid fuel, pyrolysis oils have demonstrated reasonable storage properties and decent combustion properties in low-speed and medium-speed diesel engines. The U.S., Canada and several European countries supported a research program on bio-oil production during the early to mid 1990's, including combustion characterization of bio-oils at SNL's Combustion Research Facility. In the late 1990's the U.S. program was terminated as the estimated cost of bio-oil production of about $1.50/gallon was deemed too high to be commercially viable. However, circumstances have changed and today that $1.50/gallon price tag is a bargain.

On February 1, 2007, an announcement was made that will give an enormous boost to biofuels research in the San Francisco Bay Area, with ramifications extending far beyond. Following an intense international competition, BP, the global energy corporation, selected UC Berkeley and Berkeley Lab, in partnership with the University of Illinois at Urbana-Champaign, as the recipients of an unprecedented $500 million grant to establish an Energy Biosciences Institute (EBI). Initially, the focus of research at the EBI will be on the production of biofuels from biomass sources such as switchgrass, algae and cornfield waste. This effort will dovetail with Berkeley Lab's aforementioned Helios Project, and the two programs will share a single host building, which will be constructed on the border between the two Berkeley partner institutes, in large part with funds from the California state government. The EBI goal of developing biofuels as a sustainable, carbon-neutral alternative to gasoline, also dovetails with the efforts of another major Bay Area-based initiative called the Joint BioEnergy Institute. JBEI (pronounced "jay-bay") is competing to be one of two bioenergy research centers that the DOE plans to establish through its Office of Science Genomics GTL program. The DOE proposal calls for spending $250 million on these centers over the next five years. The JBEI partnership includes Berkeley Lab, LLNL and SNL, UC Berkeley and UC Davis, and Stanford University. Should it be successful, JBEI, in combination with EBI and Helios, will bring hundreds of millions of dollars to bear on the development of biofuel technologies. With these new centers and other efforts related in this chapter, the San Francisco Bay Area is positioned to be at the intellectual center of biofuel science and technology.

ELECTROCHEMICAL AND MAGNETIC TECHNOLOGIES



Electrochemical Fuel Cell
Image courtesy of the National Renewable Energy Laboratory

Advanced electrochemical batteries and fuel cells have been called by their strongest supporters the "holy grail of energy research." Small, nonpolluting devices that produce energy without combustion, advanced electrochemical batteries and fuel cells could help meet many residential power needs or serve as stationary electrical power generators. However, their most exciting application is in transportation, as evidenced by the growing impact already being made on the automotive market with hybrid vehicles.

The introduction of hybrid-electric drivelines in passenger cars has been hailed as one of the most important new developments in automotive technology in recent years. Less than 10,000 hybrid cars were sold in 2000 when the first hybrid models were introduced; by 2005, the annual sales would exceed 200,000 vehicles. The driving force for the development and sale of hybrid vehicles is improved fuel economy (miles per gallon). A hybrid-electric vehicle driveline consists of both an internal combustion engine (ICE) and an electric motor which can also be used as a generator; when braking, the heat involved is "regenerated" to charge the battery. Electrical energy is stored on board the vehicle in a battery which is recharged by the generator while driving, using a portion of the power output of the engine. The combination of the engine and the electric motor can operate more efficiently than the engine alone, resulting in significant improvements in fuel economy. At between 30 to 60 percent higher fuel efficiency for stop-and-go driving within a city, improvements in fuel economy over a typical ICE car are large. The improvements for highway driving are smaller but still in the range of 15 to 25 percent. In comparison to conventional ICE vehicle sales, it is expected that the sales of hybrid vehicles will continue to increase in future years as the incremental cost of the hybrids decreases due to mass production efficiencies and as the price of gasoline likely remains at the current high level or possibly even increases further.

Advanced electrochemical batteries and fuel cells have been called the "holy grail of energy research" because they are small, nonpolluting devices that can produce energy without combustion. Their most immediate application is in transportation, where they are already being put to good use in hybrid vehicles.

All hybrid-electric vehicles utilize some combination of an engine, electric drive, electrical energy storage, and a transmission, but these components can be arranged and controlled in a variety of ways. One of the key distinctions in the technology alternatives is whether both the ICE and the electric motor apply torque to the wheels, or only the electric motor is connected to the wheels (parallel vs. series arrangements). Another difference is whether the battery is charged from the electricity generated onboard by the vehicle or from an outside source on a regular basis (charge sustaining vs. plug-in). In the case of the plug-in hybrid, the vehicle uses both gasoline and wall-plug electricity and the gasoline savings can be huge—as great as 85 percent depending on the daily use pattern of the vehicle. All the hybrid vehicles currently being marketed have a parallel driveline arrangement (both the engine and electric motor are connected to the wheels via a transmission) and use a battery charge-sustaining strategy. This is done to reduce the incremental cost of the hybrid vehicle relative to the conventional car and to make its refueling the same as present cars.

Today's commercially available hybrid vehicles utilize small battery units storing only 1–2 kilowatt-hours of electrical energy. These vehicles are not intended to operate on battery power over any significant distance or time. The electrical energy storage is only intended to improve the driveline efficiency, using the engine as the primary energy converter. If the electrical energy storage capacity of the battery in the "full hybrid" is increased to 6–8 kilowatt-hours, the vehicle could operate in an electric-only mode for as many as 40 to 50 miles, with the battery being recharged at night from the wall plug. For days in which the miles traveled are less than the all-electric range of the vehicle, essentially no gasoline would be used and the fuel savings would be nearly 100 percent. Hence the plug-in hybrid would have high fuel economy when operating in the hybrid mode for long trips and not use gasoline at all for short trips in town. The major reason that no automobile company presently markets a plug-in hybrid is the high cost of batteries and their uncertain cycle life for deep discharge use.

There seems to be little doubt that hybrid vehicle designs will continue to improve with increasing improvements in fuel economy in future years. Economic considerations will continue to be critical in the marketing of hybrid vehicles. This will favor charge-sustaining hybrid vehicle designs. Nevertheless the interest in plug-in hybrids is increasing and if/when battery costs become lower and gasoline prices continue to increase, the economics, as well as the petroleum savings potential, will become more favorable for the plug-in hybrid designs. Many automotive experts have now concluded that hybrid-electric driveline technology is the wave of the future and within a decade, a significant fraction of all cars sold in the U.S. will utilize that technology. In fact, BASIC members and other Bay Area institutions will play a critical role in driving the improvement of hybrid cars, particularly through new types of hybrid-electric drivelines that will utilize advanced engines, electric motors and electronics, and cheaper and more efficient electrochemical batteries and fuel cells.

One of the most well-established research programs for advanced electrochemical batteries and fuel cells is that of the Berkeley Electrochemical Research Consortium (BERC), a collaboration of Berkeley Lab and UC Berkeley. BERC manages the Batteries for Advanced Transportation Technology (BATT) program, which is the electrochemical research initiative of the DOE's FreedomCAR and Vehicle Technologies Program. BERC also produces modeling software to improve battery performance and safety. The overall goal is to develop electrochemical power sources that are suitable for electric, hybrid-electric and plug-in hybrid vehicles.

The BATT Program addresses the fundamental problems of chemical and mechanical instabilities that have impeded the development of electric, hybrid and plug-in hybrid batteries. Low-cost, abuse-tolerant batteries with higher energy, higher power, excellent low-temperature operation, and longer lifetimes are needed for all three applications. Lithium-based batteries offer the most hope in this regard. The requirement from the batteries changes for each of these applications and consequently, so do the challenges that need to be solved in order for these batteries to reach the marketplace. While hybrid-electric vehicles are widely available today, they use nickel-metal hydride (Ni-MH) batteries. Lithium ion (Li-ion) batteries provide double the specific energy and specific power compared to Ni-MH batteries, thereby allowing for significant improvements to vehicle operation. However, battery cost, and the inability to provide power at low temperatures (below -10°C) impede their use in vehicles. Additionally, a pure electric vehicle is thought to be commercially unfeasible unless the specific energy of the battery can be doubled compared to presently available Li-ion batteries. A nontrivial undertaking, this stringent requirement is needed to develop a vehicle that has the same range as presently available gasoline vehicles.

For plug-in vehicles, a battery pack larger than that used in hybrids will be needed to provide a range of approximately 30 miles. The battery will then need to be recharged via the electricity grid, similar to an electric vehicle. For longer distances, an internal combustion engine will also be needed. The dual-power source means that the cost of these vehicles is expected to be high, necessitating reduction in battery cost. In addition, it is expected that the batteries would need to undergo in excess of 3,000 charge/discharge cycles during the life of the car; another nontrivial challenge. Therefore, while the rewards for the development of these batteries are significant, the challenges are also significant and require a fundamental reenvisioning of battery operation.

The methodology used by the BATT program is to identify and better understand cell performance and lifetime limitations before initiating battery scale-up and development activities. Emphasis is placed on the synthesis of components into battery cells with determination of failure modes, while maintaining strengths in materials synthesis and evaluation, advanced diagnostics, and improved electrochemical model development. The selected battery chemistries are monitored continuously with timely substitution of more-promising components or component modifications, as appropriate. This is done with advice from within the BATT Program and from outside experts, including consultation with automotive companies and the DOE. Also factored into the BATT Program decision-making process is the continuous monitoring of battery R&D activities, including assessments carried out by others worldwide. The BATT program not only supports research on technologies that lead to incremental improvements to existing materials, but also on high-risk “leap-frog” technologies that promise to have a tremendous impact in the marketplace. This strategy constitutes a systematic screening of battery chemistries and designs that not only has a built-in methodology for reselection but also provides a clear focus for the development of new materials.

Independent of BATT, Berkeley Lab has a fuel cell research program that has spanned nearly five decades. The focus of this program has three parts. First is the development of membranes and materials amenable to fuel cell operations at low relative humidity and under the full range of operating conditions including high and low temperatures. Second is the fundamental study of fuel cell electrocatalysis, including both synthesizing and characterizing novel and traditional catalytic materials and pathways. Third is the mathematical modeling of fuel cell phenomena on a fundamental physical level. Among the notable successes of this program were the development of an electro-active polymer that prevents Li-ion batteries from being overcharged; development of a novel means of coating poorly-conductive battery-active materials with conductive carbon using both microwave techniques and high-temperature treatments; development of block-copolymer-based solid-polymer-electrolyte membranes that hold promise in making lithium metal-based batteries a reality; and development of a standardized methodology to compare various battery chemistries.

Also working at the fundamental level of fuel cell studies are the researchers at UC Davis' NEAT (Nanomaterials in the Environment, Agriculture, and Technology) research and education program. The main thrust here is to analyze rare earth oxides at high temperatures in order to elucidate surface energies and defect formation. These compounds can potentially be used in thin-film solid-oxide fuel cells with potential implications in fuel cell efficiency, longevity and environmental safety.

LLNL researchers pioneered development of zinc/air and aluminum/air batteries but have recently focused on thin-film fuel cells. LLNL researchers also invented the carbon aerogel that led to the formation of Powerstor, based in Dublin, California, a subsidiary of Cooper Electronics. Powerstor is a successful manufacturer of supercapacitors based on LLNL's carbon aerogel material, and it manufactures and markets supercapacitors for applications like portable electronics.

LLNL researchers are also heavily involved in another promising approach to energy storage called an "electromechanical" (E-M) battery. An E-M battery is an energy storage module containing a high-speed flywheel rotor, fabricated from fiber composites—light, yet strong, aerospace materials. To spin up the rotor and to withdraw the energy in electrical form, the rotor is fitted with an integrally mounted generator/motor. The rotor operates at high speed, in vacuum, inside a hermetically sealed enclosure, supported by a "magnetic bearing," that is, a bearing that uses magnetic forces to support the rotor against gravity. Magnetic bearings are a virtual necessity for the E-M battery in order to achieve long service life, and to minimize frictional losses so that the battery does not lose its charge (run down) too rapidly. These considerations mitigate against the use of conventional mechanical bearings in the E-M battery for most applications.

To meet the special requirements of the E-M battery, LLNL researchers pioneered the development of the "ambient-temperature passive magnetic bearing," a new form of magnetic bearing using permanent magnets. Because they are simpler and potentially much less expensive than the existing "active" magnetic bearings (those requiring electronic amplifiers and feedback circuits for their operation), the development of ambient-temperature passive magnetic bearings represents a technological breakthrough.

Beyond its use in the E-M battery, the ambient-temperature magnetic bearing could have important applications in replacing conventional lubricated mechanical bearings in electrical machinery. Here the gains would be twofold: reduced frictional losses, leading to higher motor efficiency; and, of equal importance, the elimination of the need for lubricants and for routine replacement of the bearings owing to mechanical wear. When perfected, passive magnetic bearings represent an almost ideal replacement for the mechanical bearings in many types of industrial electrical machinery.

Stanford Research Institute (SRI) has research programs that encompass batteries, supercapacitors and fuel cells. One program is the development of a nonflammable electrolyte to improve the safety of Li-ion batteries. Altogether, SRI has spun off two fuel cell development companies, PolyFuel, Inc. and PowerZyme,Inc., which are seeking to successfully commercialize SRI's battery and supercapacitor research results.

In addition to advanced batteries, two other areas of research hold special interest for hybrid vehicles: (1) ultracapacitors as electrical energy storage for mild hybrid vehicles; and (2) the design and testing of plug-in hybrid vehicles of various classes from subcompact to large SUVs.

Researchers at UC Davis have made important contributions in developing commercially viable ultracapacitors. Ultracapacitors are constructed much like a battery, but function more like a conventional dielectric capacitor in that the electrical energy is stored as charge separation in microscopic pores in the electrode material. Ultracapacitors are often referred to as supercapacitors or electrochemical capacitors because the energy density of ultracapacitors is much lower than that of batteries. However, the power density of the capacitor is much higher than that of batteries (1500–2500 W/kg versus 200–500 W/kg). In addition, the cycle life of ultracapacitors can be 500,000 to one million deep-discharge cycles. Comparable values for a battery are 500–2000. The special characteristics of ultracapacitors make them ideal components for use as energy storage in mild hybrid vehicles for which the quantity of energy storage is substantially less than that in passenger car applications.

Ultracapacitor development for vehicle applications started in 1990 and has continued to the present. Most of this research effort has dealt with the use of high-surface-area activated carbon as the electrode material. Large devices are now available as commercial products. Many of these devices have been tested at UC Davis and their characteristics reported in the literature. Demonstrations of the use of ultracapacitors in hybrid vehicles, especially transit buses, has been underway for several years, and presently there is renewed interest in their application in passenger cars. To date, the high cost of ultracapacitors has been the primary reason that batteries rather the ultracapacitors have been used in all hybrid passenger cars.

UC Davis researchers are seeking ways to increase the energy density and lower the cost of ultracapacitor-like devices. One project involves the combination of an activated carbon electrode from a carbon/carbon ultracapacitor with the positive lead oxide ($PbO_{2)}$ electrode from a lead-acid battery. Assembly and testing of small devices in the laboratory have shown that energy densities in the range of 10–15 Wh/kg and power densities of 1000–1500 W/kg are achievable with this hybrid ultracapacitor approach. The characteristics of the carbon/PbO_2 device compare favorably with other energy storage technologies in both performance and cost. Cycle life is the major uncertainty concerning the carbon/PbO_2 device because of corrosion of the positive lead electrode current collector.

Since 1993, in addition to improving batteries, teams of researchers at UC Davis have designed, constructed, and tested hybrid vehicles in the DOE-sponsored Future Car and Future Truck programs. These competitions have involved up to seventeen universities in the United

States and Canada. All the UC Davis vehicles have been plug-in hybrids utilizing parallel hybrid driveline arrangements. The plug-in hybrid designs are most appropriate for California and consistent with the Zero Emission Vehicle mandate. The vehicles have good performance in the all-electric mode and all-electric ranges of 50–60 miles using nickel metal hydride batteries. The electric motors and engines have comparable power ratings of 50–90 kilowatts. The downsizing of the engine from that in a conventional ICE vehicle results in large improvements (40–50 percent) in fuel economy in both city and highway driving when the vehicles are operated in the hybrid mode (combined electric and engine power). For a typical car owner, the extended all-electric range would result in an annual gasoline savings of at least 80 percent because most of the city driving would be done using battery electricity from a wall plug rather than gasoline. The UC Davis hybrids are also designed to operate on mixtures of gasoline and ethanol (up to 85 percent ethanol). This is a second way to save gasoline/petroleum and use alternative sources (biomass) for vehicle fuels.

A number of startup companies, many of them spin-offs of research from the national labs, are also at the forefront of battery and ultracapacitor research and development.

PolyPlus Battery Company is a Berkeley developer of advanced batteries. Founded in 1990 with technology that originated at Berkeley Lab, Polyplus was one of the original developers of lithium/sulfur batteries and has recently developed a “protected” lithium electrode that may enable both ultra-high-energy-density lithium/air and lithium/sulfur batteries.

Based in Hayward, California, Farasis Energy is a startup engaged in battery- and energy-related research. Farasis Energy received Department of Energy and Office of Naval Research funding for programs to develop high-capacity anode materials for Li-ion batteries, advanced high-power cathode materials for Li-ion hybrid vehicle batteries, and novel life-projection methods for hybrid vehicle batteries, fuel cell catalysts and hydrogen storage.

Battery Design Company, based in Pleasanton, California, and Columbia, South Carolina, develops software to aid battery designers and manufacturers. Researchers at Battery Design have developed software to optimize battery energy density and power density for applications such as hybrid vehicles.

Another Bay Area startup company, Nanoexa, utilizes its computational models to improve material performance in clean energy products, including Li-ion batteries. Nanoexa’s models offer an innovative way to design and validate material design from the quantum level, thus fostering the development of novel materials and accelerating the improvement cycle of current materials. The company’s current focus is on Li-ion batteries for hybrid vehicles and portable devices with subsequent applications in solar cells.

During the next five years, the production and sales of hybrid vehicles will continue to grow. Given the current research by BASIC members and at startup companies around the Bay Area, high power Li-ion batteries will replace conventional nickel batteries once safety and cost issues have been resolved. This would position the Bay Area and its research and entrepreneurial base for establishing a preferred network with the Asian companies that currently develop and manufacture hybrid vehicle batteries.

Even with the continued evolution of the hybrid vehicle, the greatest potential savings in transportation energy expenditures will come from meeting the daily transportation needs of massive numbers of urban commuters. The daily commute to and from the work place in the U.S. remains a major factor in the consumption of imported petroleum. The introduction of mass transportation alternatives to the currently limited bus, subway, and light-rail systems is widely believed to be the key to drastically reducing the demand for transportation fuels.

LLNL researchers may have found an answer to the present mass transit problems. Arising from fundamental studies of electromagnetism, a new and simpler breed of maglev (magnetic levitation) train has been researched at LLNL since the late 1990s. Now licensed to the General Atomics Corporation in San Diego, the Livermore "Inductrack" maglev approach is well on the way to its first commercialization as an urban mass-transit alternative to light-rail systems and city buses.

The concept of the maglev train has been with us for decades. Germany and Japan funded R&D programs involving billions of dollars and decades of effort that produced engineering marvels in the form of maglev trains that have attained speeds of 300 miles per hour or more on test-track runs. Yet despite these impressive results, only one such maglev "showcase" train (between Shanghai and its airport) has been constructed and is now being operated commercially. The problem lies in the cost and technical complexity of current maglev technologies. The Chinese are using a maglev based on the German "TransRapid" technology, in which levitation is achieved by employing an array of electromagnets underneath the train cars. These electromagnets levitate the train cars by being attracted upward toward steel rails. This form of magnetic levitation is intrinsically unstable. The Japanese "Yamanashi" maglev test train employs large superconducting magnet coils embedded in the sidewalls of the train cars to produce the intense magnetic fields needed for levitation. These magnetic fields levitate the train (when it is moving faster than a "lift-off" speed of about 100 mph) by their interaction with electrical coils embedded in concrete walls running parallel to the train track. Superconducting magnets operate at the temperature of liquid helium (4 degrees above absolute zero), which means they require complicated and reliable onboard cryogenic refrigerators to maintain their low temperature, plus highly effective magnetic shielding inside the train compartment to shield those with pacemakers from the intense magnetic fields.

The LLNL Inductrack maglev system involves a technology that is simpler and very different from the German or the Japanese systems. Instead of using superconducting magnets or servo-controlled powered electromagnets to provide levitation, special arrays of permanent magnets are employed. In the 1980s, Berkeley Lab's Klaus Halbach performed research on optimum ways to configure an array of permanent-magnet bars for the purpose of focusing and directing charged particle beams. His planar "Halbach Arrays" have the property of concentrating the magnetic field on the lower surface of the array, while canceling it above the array, thus making the most effective use of the magnetic material. The periodically varying magnet field below the Halbach array, which he devised in order to focus charged particle beams, was ideally suited for a new approach to magnetic levitation. At about the same time Halbach was carrying out his studies, a new type of permanent-magnet material was discovered—an alloy of neodymium, iron, and boron (NdFeB)—that is much more powerful than older magnet materials, such as the familiar alnico magnets used in loud speakers, or the ceramic ferrite magnets we use to hold pictures and notes on our refrigerators. This new material, abbreviated as NdFeB, is now in large-scale production for such varied uses as computer hard drives and powerful electric motors for hybrid automobiles.

The Halbach array constructed using NdFeB magnets is a key element in LLNL's Inductrack maglev system. Permanent-magnet arrays, mounted underneath the train cars, glide an inch or two above special tracks. These tracks are composed of a half-inch-thick laminated stack of copper or aluminum sheets. Each of these sheets has etched into it a pattern of transverse slots that end within an inch or so from the edges of the sheets. Slotting the sheets in this way creates a pattern of electrical circuits, shorted at their ends. When the train car moves above such a track, the spatially periodic magnetic field of the Halbach arrays will, by electric generator action, produce strong transversely directed electrical currents. The magnetic field from these currents interacts back on the magnetic field of the Halbach array, producing a repelling force that levitates the train car. In contrast with the 100 mph lift-off speed of the Japanese maglev train, the levitation force of the Inductrack becomes effective as soon as the train car reaches walking speeds. Above this speed, the train car will lift off its auxiliary wheels and remain stably levitated. The Inductrack is thus a truly "fail-safe" system, in that no power is required to produce the levitating magnetic fields, and, unlike the TransRapid, the levitation is intrinsically stable. Furthermore, should its drive power fail, the train car will remain levitated until it slows to walking speeds, then settle gently down onto its auxiliary wheels. The Halbach array and NdFeB magnets result in very strong levitation forces. The Inductrack can be designed to lift in excess of 50 metric tonnes per square meter of Halbach array. (One metric tonne equals 1,000 kilograms or 2,200 lbs.) The portion of the Halbach arrays required to levitate each passenger is equal in area to that of a postage stamp.

Either an electric drive or, in open country, a turbojet drive could be employed to drive an Inductrack maglev train. The electric drive system being implemented by General Atomics is called a "Linear Synchronous Motor" (LSM). In an LSM, a wiggly pattern of conductors carrying AC currents driven by a variable-frequency source of electric power, is imbedded in the track. The magnetic field from these windings then interacts with another Halbach array located underneath the train car to produce driving and braking forces. There is no high-voltage "third rail" and no onboard power other than "housekeeping" power for communication, heating, air-conditioning and lighting. The Inductrack can achieve very high drive efficiencies against minimal drag loss. In a maglev train like the Inductrack, there are no frictional drag losses but there are electromagnetic drag forces associated with the power dissipated resistively in the track windings.

A measure of the levitation efficiency of a maglev system, like that of an airplane, is the Lift-to-Drag (L/D) ratio. Jet airplanes typically have L/D ratios of about 25 to 1. But Inductrack systems can easily be designed to have L/D ratios of 200 to 1 or more at operating speeds. For Inductrack maglev systems operating at urban speeds, where aerodynamic losses are generally small, the overall energy efficiency can be made to be substantially higher than that of typical light-rail or bus systems. For example, in a parallel development at LLNL, a highly efficient drive system for the Inductrack was designed that would automatically recover the braking energy from the train and return it in electrical form to the power grid.

Studies at General Atomics have confirmed the cost advantages of the Inductrack in several settings. For example, a comparison study with a light-rail system proposed for an eastern city in the U.S. showed that the Inductrack was far less expensive. Furthermore, the Inductrack can operate on an elevated track, navigate sharp turns and steep grades, and run essentially noiseless.

General Atomics has been performing development work under the primary sponsorship of the Federal Transit Administration. Their task is to develop a "generic" urban maglev system, one that might be deployed in any major U.S. city or suburb. Their working team is composed of several engineering firms in Pittsburgh, Pennsylvania, together with Booz-Allen-Hamilton in San Francisco, and LLNL.

To date this team has been able to analyze, design, and construct a full-scale test track and test train car. They have also designed all of the major components of a working system—train cars, track and support structures, stations, and electrical drive systems—and have addressed all of the required control and safety issues. It is now possible to predict the operating characteristics of an Inductrack system with high accuracy. The computer codes, benchmarked against experimental measurements on test rigs at LLNL and General Atomics, allow one to calculate and optimize the potential performance of Inductrack systems, thereby greatly shortening the development time for achieving an operating system.

Taking a leap into the future, one can envisage a network of such urban maglev systems, operating between intermodal terminals throughout a city and its suburbs. This can then be coupled with the idea of linking the network to a central intermodal terminal where high-speed versions of the Inductrack enter and leave, providing rapid, safe, and silken-smooth inter-city mass transit. Studies abroad have even looked at the possibility of using maglev trains as high-speed shuttles between cities for automobiles and their passengers. Finally, as feeders to an urban maglev system, LLNL researchers have visualized "people mover" pods, using Inductrack magnetic levitation, allowing commuters to board the system at stations throughout residential as well as business areas.

GEOTHERMAL ENERGY


Geyser
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Chapter Three: Geothermal Energy

Geothermal energy, the heat that originates from deep below the earth's surface, is both renewable (if managed properly) and environmentally benign. It also leaves no scars upon the land in the form of open pits, mineshafts or tunnels, nor does its use create wastes that must be dealt with. Since no fuel is burned during the operation of a geothermal power plant, it is carbon-neutral compared to fossil fuel plants, and produces none of the nitrous oxide or sulfur gases that deplete our precious ozone layer. Perhaps equally important, geothermal energy does not have to be imported to the United States. While geothermal energy technology has been around for more than 100 years and is used in the United States today to generate nearly 3,000 megawatts of power, with improvements in the technology, thousands of megawatts more could be readily generated.

Geothermal energy, the heat that originates from deep below the earth's surface, is renewable, environmentally benign and plentiful in the United States. It also leaves no scars upon the land in the form of open pits, mineshafts or tunnels, nor does its use create waste.

Geothermal power plants use superheated fluids from the earth's geothermal resources to generate electricity. Over thousands of years, rainwater has seeped through cracks in the earth's surface and collected in underground reservoirs. Magma, the molten rock surrounding the earth's core, heats this water until it becomes a superheated fluid. As this superheated fluid flows towards the planet surface, pressure decreases, causing a small portion of the fluid still within the well to separate or "flash" into steam. At the surface, the superheated fluid and steam mixture flows through surface pipelines and into the power plant's wellhead separator. Inside the separator, the pressure of the superheated fluid is further reduced. This causes a large amount of the superheated fluid to rapidly vaporize and flash into high-pressure steam. The steam is delivered to a turbine, which transforms the geothermal energy into mechanical energy. The fluid that is not flashed into steam flows into the reactor clarifier system and is then returned to the geothermal reservoir through injection wells.

California leads the nation in installed geothermal capacity, yet there are still significant additional unexploited geothermal resources, especially around the Bay Area. R&D by BASIC member institutes and other Bay Area organizations is leading to continuously more effective and efficient development of the geothermal resource base for California and the rest of the nation. The ultimate goal is to make geothermal energy an economically competitive contributor to the U.S. energy supply. Not only can the earth's heat be used to produce electricity, but it can also heat and cool buildings and be used as a source of piped hot water for a wide variety of applications, including district heating, aquaculture and greenhouses.

Geothermal resources are usually difficult to locate and characterize. For this reason, still undiscovered hydrothermal resources have been termed “hidden” resources. The success rate for finding economic resources at previously undrilled sites is relatively low (estimated at 20 percent), and it is expensive to drill deep wells. New, rapid, inexpensive screening techniques are needed to remotely and reliably detect and image geothermal reservoirs before drilling for these resources. Successful discoveries will require new ways of integrating disparate sets of geological, geochemical, and geophysical data. Once a geothermal field is in operation, it will be critical to optimize field management practices based on improved reservoir characterization techniques.

Relatively mature and robust technologies are available for direct-use applications, heat pumps and even for electricity generation from mid- to high-temperature shallow resources. However, the major technical challenges being tackled by Bay Area researchers and laboratories include: 1) locating geothermal resources that are “hidden” without easily detectable surface manifestations; 2) optimizing production from existing geothermal fields; and 3) developing and deploying the technology needed to economically capture the larger, deeper, cooler and less permeable resource base.

To overcome these technical challenges, the DOE has created the Enhanced Geothermal System (EGS) program. Many geothermal researchers in the Bay Area are exploring enhanced geothermal systems as the key to maximizing the utilization of the earth’s heat. In EGS, a subsurface fluid circulation system (similar to a natural hydrothermal system) of optimal volume and fluid-rock contact area is artificially created and managed over time. Specific challenges include: more accurate remote targeting of elevated temperatures; remote detection of favorable stress regimes that will help to keep fractures open at depth; improved techniques for creating and maintaining artificially created fractures; and simulation/modeling tools for predicting, managing and monitoring system performance.

A large number of companies in the Bay Area and in neighboring Sacramento are involved in the geothermal industry. Those involved range from individual consultants, to small- and medium-sized consulting companies (Two-Phase Engineering and Research and GeothermEx), to large corporations (Calpine and Chevron Geothermal). The scientific and engineering expertise represented by these companies is far-ranging, including, but not limited to: economic and project evaluations, governmental/regulatory issues, direct use, construction, engineering design, environmental and geological services, exploration, reservoir assessment, operations and maintenance, chemical services, emission control, and educational outreach. Many of these companies are located in the Bay Area because of the proximity to The Geysers near Middletown, California, one of the most productive geothermal fields in the world. Several BASIC members have been at the forefront of geothermal research and development, including Stanford, Berkeley Lab, and LLNL. The U.S. Geological

Survey (USGS) is located in Menlo Park and, in addition, the Geothermal Education Office, located in Tiburon, California, promotes the public's understanding of geothermal resources.

In Sacramento, the California Energy Commission's Geothermal Program and the California Geothermal Energy Collaborative are addressing regulatory and governmental issues such as leasing, permitting, and a more reliable transmission system for renewables, as well as promoting education about geothermal energy. The Commission also promotes California geothermal development by extending financial and technical assistance to public and private entities. Examples of funded projects include resource assessments, new logging tools, space heating and direct-use projects. The Southeast Geysers effluent pipeline project, supplying water for reinjection at The Geysers, is significantly increasing the power output from that field.

Stanford's geothermal program focuses on geothermal reservoir engineering techniques with both numerical modeling and experiments. The current research emphasis is on reinjection into vapor-dominated reservoirs such as The Geysers. This program has produced a large number of graduate engineers who now work in the geothermal industry throughout the world.

The USGS is updating their assessment of U.S. geothermal resources to develop supply curves for both hydrothermal and EGS. Researchers at the USGS and Stanford have teamed to make important discoveries concerning the control of optimally oriented, critically stressed fractures on well productivity.

The research at Berkeley Lab and LLNL spans exploration, resource development, reservoir management and EGS, and integrates disciplines represented by geology, geophysics, hydrology, geochemistry, isotope chemistry, and rock mechanics. Berkeley Lab researchers are developing computer codes that simulate physical and chemical processes in geothermal systems. They are also piloting the use of noble gases and isotopic techniques to track fluid flow; designing 3D seismic imaging and micro earthquake studies of reservoirs; setting up the joint inversion of geophysical data sets; and implementing field case studies. LLNL researchers are using low abundance isotopes to track fluid flow; applying new techniques for simultaneously using many kinds of disparate data to refine conceptual models of complex geologic systems; using air- and space-based remote sensing techniques to detect hidden systems; using a combination of experiments and modeling to evaluate the chemo-thermo-mechanical evolution of fractures; and developing methods to extract valuable by-products from geothermal fluids.

One particularly promising EGS test is being carried out at the Desert Peak geothermal field by a Bay Area company, GeothermEx, Inc. of Richmond, in conjunction with one of the major geothermal system manufacturers, Ormat. This project involves hydraulically fracturing a nonproductive well in the Desert Peak geothermal field in Nevada to artificially create a subsurface circulation system between two wells that can be used to power a 2–5 megawatt binary plant. This project is aimed at determining the technical and economic feasibility of creating an enhanced geothermal system. To date, geological, geophysical and geochemical characterizations of the well and its environs have been carried out to assess its potential for hydraulic stimulation. Plans call for hydraulic fracturing, followed by drilling of another well to attempt to complete a circulation loop. Projects such as this are aimed at demonstrating the ability to create an EGS system and its dominant processes, and providing the lessons learned to make it possible for other operators to create their own EGS systems.

In addition, a group of researchers from the USGS in Menlo Park, Stanford, and the Menlo Park office of Geomechanics International have collaborated on studies relating fractured rock hydrology to *in-situ* stress and recent deformation at the Dixie Valley geothermal field in Nevada. Their work showed that optimally oriented, critically stressed fractures control permeability (and thus well productivity) in areas of active tectonics, and may be essential to the success of EGS projects. This finding points to the need to develop a geomechanical model of a potential reservoir, a process which currently requires a wellbore for the acquisition of modeling data. The future challenge is to develop geophysical and/or remote sensing techniques which, in combination with surface geologic information, can be used to reliably predict the stress state and fracture permeability at depth. The use of such techniques significantly reduces exploration and resource assessment costs.

Chemical and isotopic methods are the only technologies available for confirming the existence of hot fluids at depth during exploration, identifying the source of geothermal fluids and heat, and defining the geometry and extent of a resource. Current studies at Berkeley Lab's Center for Isotope Geochemistry suggest that noble gas isotopes may be useful in determining which range front faults in the Basin and Range Province have deep fluid circulation with good geothermal potential. LLNL has employed accelerator mass spectrometry to measure extremely low-abundance isotopes such as chloride-36, which have been critical to identifying fluid flow pathways and mixing relationships. These new isotopic measurements and techniques should significantly reduce the uncertainties associated with locating new resources (especially hidden systems) and with reservoir characterization.

Reservoir management is of critical importance once a geothermal field has been developed. A good example is The Geysers field, which began to experience steep declines in production in the late 1980s due to a combination of overexploitation and inadequate water reinjection/recharge. Starting in 1997, the Southeast Geysers Effluent Project began bringing an external source of injection water to the field. This stopped reservoir decline, helped increase electricity production from The Geysers, and also helped Lake County meet state-mandated discharge limits. Currently the Santa Rosa Geysers Recharge Project is also piping tertiary-treated municipal wastewater to The Geysers to supplement reinjection.

At LLNL, remote sensing techniques are being developed to screen large spatial regions to find the most likely locations for further exploration field expansion efforts. And Berkeley Lab is developing remote sensing techniques for evaluating a system's response to production. LLNL, in collaboration with UC Santa Cruz faculty and students, performed the evaluation of the first of these remote sensing tools. Now nearing commercial use, high-resolution hyperspectral airborne imagery relies on the unique spectral signatures of plants and minerals to map soil types, vegetation, high-temperature mineralization, springs, and hidden faults.

InSAR (repeat-orbit synthetic aperture radar interferometry) is being evaluated as a regional reconnaissance tool by testing its capability to detect localized strain anomalies hypothesized to be associated with fault-hosted geothermal systems. InSAR is a satellite-based geodetic technique that has the potential to measure surface strains on the order of 10^{-6} to 10^{-7} on a regional scale with a spatial resolution of 25 meters, and it fills in the gaps between single point GPS stations. Work at Berkeley Lab and LLNL has also shown that InSAR's detection of surface deformation over producing geothermal fields can be used to evaluate the impact of production on the reservoir and fluid flow.

As the wide range of technical, regulatory and public outreach work being currently implemented by Bay Area organizations continues and is conducted in an integrated, collaborative fashion among private and public entities, geothermal energy will be recognized and utilized as an essential green component of the nation's energy supply. Through the California Energy Commission, the state government is being proactive in helping industry meet California's renewable portfolio standards. With sufficient attention and a sense of urgency, the regulatory and governmental issues can be largely addressed in 3 to 5 years. It is also possible that the technical and economic feasibility of EGS will be demonstrated by Bay Area researchers at Desert Peak, and that project will serve as a lessons-learned example to encourage and guide other industry EGS projects. With the science of reinjection and other reservoir management techniques better understood and best-practices refined, it should be possible to maximize production from geothermal fields and extend their lifetimes indefinitely. In addition, with new technologies based on conceptual and simulation science, the faint signals of hidden geothermal systems will be much easier to detect in the future.

HYDROGEN FUEL

HYDROGEN FUEL

Hydrogen in a Bottle
Image courtesy of the National Renewable Energy Laboratory

For its transportation energy, the United States depends almost entirely on petroleum fuels (97 percent). Currently, this translates into the consumption of approximately 200 billion gallons per year of nonrenewable petroleum-based (gasoline and diesel) products. One of the most politically popular options for losing our gas-guzzling ways is hydrogen. The use of hydrogen as an energy carrier for vehicles opens up the possibility of zero emissions when a fuel cell is utilized. This would allow for an efficient and sustainable transportation solution that will accommodate the expected increase in vehicle numbers without unacceptable degradation of the environment. However, zero emission vehicles are not the full story since the pathway by which the hydrogen is made will influence the total "well-to-wheels" emissions. Many of the technologies that could be employed are still at an early stage of development and are not yet commercial. As a result, it is likely that near-term compromises will have to be made along the road to the hydrogen economy.

Hydrogen can be generated in various ways. The relative attractiveness of the options depends on feedstock availability, existing energy infrastructure, public policy and assorted economic factors. In areas where a well-developed infrastructure for distributing natural gas is present, on-site gas reforming is a feasible option for generating hydrogen.

While some have advocated for a move to "green" hydrogen made from renewable sources, as opposed to "black" hydrogen made from fossil (i.e., CO_2-emitting) sources, the current state of technology is such that renewable-based hydrogen will, at the present time, have a higher cost structure as well as be constrained by limited renewable resource availability. Based on economic constraints, hydrogen at this early stage will likely be made from natural gas in order to achieve a least-cost solution. Experience gained during this initial period, when hydrogen infrastructures are demonstrated and tested, will influence long-term choices for hydrogen production and distribution. In the interim, many of the societal benefits of using hydrogen can be achieved by adding hydrogen to existing compressed natural gas (CNG) vehicle fuel. Typically, blends of up to 30 percent can be made that reduce vehicle emissions while requiring almost no modifications to the CNG engine. Various companies have proprietary dispensers that can blend CNG and hydrogen and several engine manufacturers have experience running heavy duty engines on CNG/hydrogen blends.

Depending on the feedstock and production technology, the potential hydrogen infrastructure includes a range of possibilities from large to small scale. It seems likely that initial plants will be small-scale distributed facilities with on-site generation of hydrogen. Later, as economies of scale allow, large regional gasification plants could be put in place with a pipeline

Hydrogen fuel cells for vehicles have been dubbed "the ultimate green dream" in transportation energy because they can generate electricity with only water as a byproduct. Unlike batteries, hydrogen fuel cells do not require recharging, but rely on a supply of hydrogen and access to oxygen from the atmosphere.

or truck distribution systems supplying hydrogen to multiple retail sites. The current 2005–2010 hydrogen demonstration period involves centrally located, controlled vehicle fleets that do not support a retail hydrogen-station model. Beyond this timeframe the economics of hydrogen distribution may depend on the extent to which large numbers of vehicles can be located in common areas, such as government, postal service or school bus fleets, since transportation of centrally produced hydrogen into a growing, disaggregated retail demand may not be sustainable. On the other hand, future distributed reforming of natural gas (or other feedstocks) at service stations, or other discrete outlets, may have the potential to be both economic and a viable extension to the current retail model.

One concept that will be tested during the 2005–2010 demonstration period is the dual-use energy station that produces both high-quality electrical power and hydrogen for fuel-cell-powered vehicles. Hydrogen energy stations are being investigated at two scales: 50–75 kilowatts for local power supply; and 100–250 kilowatts for both local power and supply to the grid. An attraction of dual-use stations is that selling electricity to the grid may make them economically feasible in the near term while fuel cell vehicle fleets grow to a critical mass that makes vehicle fueling economic in its own right.

It will be at least 2010 before suppliers and consumers will have had sufficient experience with infrastructure and vehicles to make a judgment about the infrastructure model and hydrogen's long-term role relative to conventional fuels. What is clear, though, is that because of advances in fuel cell technology, hydrogen is poised to play an increasingly important role in the world's energy mix. A fuel cell can convert hydrogen directly into electricity for both transportation and stationary-power applications. A fuel cell converts energy very efficiently, which helps conserve energy resources, and the only by-product of this chemical process is pure water—a clear benefit for the environment. However, there is a challenge that comes with this promise of clean, abundant, secure energy. Hydrogen is not found freely in nature: it must be extracted from other substances. As a result, there are substantial technical hurdles to producing, storing, and distributing hydrogen.

For decades, Chevron Corporation has been a long-term producer of mass quantities of hydrogen—more than four hundred million cubic feet a day—for industrial use in its refineries. Chevron is also recognized for its expertise in catalysis and reforming, which are processes that allow hydrocarbons to be tailored for specific uses. Thus, converting hydrogen into a high-value energy carrier is a natural extension of Chevron's current operations. Accordingly, Chevron Technology Ventures is investing more than $120 million per year as venture capital for companies with promising hydrogen technologies; for its in-house research; and for partnerships to develop, demonstrate, and commercialize the best hydrogen production and distribution solutions.

In preparation for the increasing demand for hydrogen as an energy source, Chevron is currently creating integrated infrastructure solutions for early, non-consumer markets. Chevron's infrastructure team is developing better ways to generate, store, distribute and dispense hydrogen fuel for a range of applications, while at the same time actively participating in technical organizations that are developing standards for the design and operation of the different components of the hydrogen infrastructure.

Not only does Chevron produce hydrogen fuel on-site, but the company has integrated all the other elements of the fueling process in a single efficient, effective system designed to validate the technologies. This cohesive infrastructure incorporates innovative ways to produce, compress, purify, store and dispense hydrogen fuel. One current project that Chevron is implementing in the Bay Area is a steam methane reformer that is being built in partnership with the State of California and the Alameda-Contra Costa County Regional Transit Authority in order to fuel a fleet of fuel cell hybrid-powered buses and light-duty vehicles. Chevron is implementing other hydrogen fleet and infrastructure demonstration projects in Southern California and throughout the nation.

Integrating hydrogen into the world's energy supply will be an enormous undertaking that calls for close collaboration and partnership with governments, universities and industries worldwide. BASIC member UC Davis has a Hydrogen Pathways program that is developing new and innovative tools to better understand the technological, economic, social and environmental characteristics of hydrogen energy systems. UC Davis researchers have developed an interactive tool for modeling hydrogen demand and methods for optimizing production, distribution and refueling station infrastructure based on geographic characteristics. In addition, UC Davis researchers developed the Steady State City Hydrogen System Model (SSCHSM) that estimates the steady state cost and low-cost pathway for 73 of the largest cities in the United States. The main focus of the modeling effort is to create a program structure that provides an estimate of the infrastructure requirements and comparative costs based upon differences in city size and population, feedstock prices, and electric grid characteristics.

Hydrogen can be produced by many methods, including the reformation of natural gas, the gasification of coal, and the electrolysis of water. Production from coal is really only suitable for large-scale, centralized production. But reforming natural gas and electrolysis can be operated either at large scales in centralized plants or at small scales in smaller fueling stations. Large-scale, centralized production can produce hydrogen relatively cheaply, but requires a major investment in a distribution infrastructure. Conversely, distributed production is more expensive, but the infrastructure in natural gas pipelines and the electric distribution systems is already in place.

It is expected that production will start out on a small scale when demand is small. In some regions, demand will grow to the point where centralized production with a dedicated distribution system will become economical. The UC Davis team is developing analyses to identify the conditions that favor each approach, and to map out the possible transition to hydrogen in different regions. Their analysis system includes Geographic Information System (GIS) databases, vehicle choice models, transportation models, hydrogen production system models, mathematical programming, and engineering-economic models to identify the most economical and practical ways to meet a growing demand. Ultimately, the goals of the UC Davis team are to determine the best ways to ramp up the supply of hydrogen as demand increases and the best ways to structure the supply system once hydrogen fully penetrates the market.

SNL researchers are developing models to analyze the cost and efficiency of producing and delivering hydrogen. The Hydrogen Futures Simulation Model (H2Sim) predicts the cost of hydrogen produced by various methods (e.g., steam-methane reforming, coal gasification, or electrolysis) using power from conventional sources (including coal, gas and nuclear plants) or renewable sources (including wind and photovoltaic). The model includes the economics of sequestering carbon dioxide from coal gasification, and steam-methane reforming. After hydrogen production, the model considers a variety of options for hydrogen storage, distribution by trucks and pipelines, and utilization for transportation in vehicles powered by hydrogen engines, fuel cells, or hybrid drive trains. Key outputs include: delivered hydrogen costs versus costs per gallon of gas equivalent; key environmental effluents (carbon dioxide); and end-user costs (cost per vehicle mile driven). H2Sim provides a handy tool for policymakers to explore the feasibility of moving toward a hydrogen-based energy system.

Since a hydrogen infrastructure based on centralized production requires building an expensive distribution system, distributed production of hydrogen may be an attractive option. Even if centralized production is the best option, the transition to widespread hydrogen distribution will likely begin with distributed generation of hydrogen. SNL researchers are currently developing an engineering tool for distributed hydrogen generation sites. The tool provides a library of modules that consider thermodynamic efficiency for components such as reformers, electrolyzers, wind turbines, photovoltaic solar collectors, and fuel cells. Combined with the engineering analysis is economic analysis for leveling the cost of producing hydrogen from the various components over their expected life.

To expand the simulation of a possible hydrogen infrastructure to a larger scale, SNL researchers are applying a high-level-architecture approach to linking existing models of the hydrogen supply chain to form a macro-system model of the hydrogen infrastructure. SNL's software simulation tools can provide a unifying framework for integrating existing models from the energy systems analysis community. The DOE has recognized a need for such a macro-system framework to understand how the current fossil fuel energy infrastructure might evolve and how to guide the evolution toward hydrogen.

One of the open questions about the hydrogen infrastructure is how the hydrogen itself will be stored. In fact, widespread use of hydrogen has been challenging because of its low energy density relative to conventional (hydrocarbon) fuels. Energy density fundamentally drives the feasibility of hydrogen fuel by determining the capital, materials, volume, and energy needed for onboard storage. At this point, the technologies for storing hydrogen on vehicles have not developed to a level appropriate for mass production. The intrinsically low energy density and special conditions of hydrogen storage (e.g. cryogenic temperatures, high pressures) present challenges, especially in a retail context.

LLNL researchers are conducting research on nonconventional pressure vessels for containment of compressed and liquid hydrogen storage. Two promising approaches currently being explored are conformable pressure tanks/vessels and cryogenic-compatible pressure tanks.

To improve the practicality of hydrogen as a transportation fuel, conformable tanks can be designed to optimally occupy available space in vehicles, minimizing intrusion into cargo spaces. Cylindrical or spherical shapes are the easiest for pressure tank fabrication, but available spaces inside vehicles are typically not cylindrical or spherical. Better utilization of available spaces in vehicles is the key to achieving hydrogen storage targets without reducing vehicle practicality. Two parallel paths to conformability are being pursued. The first uses filament-winding techniques, and is moving from analysis into the test stage. The second path uses an innovative macro-lattice approach in which the pressure loads are supported by an internal structure, and the vessel skin is for hydrogen containment only. This approach is in the early development stage. The first macro-lattice pressure vessel was delivered in 2005, and new designs with improved pressure performance are planned for the next years.

Cryogenic compatible pressure tanks or vessels offer an attractive alternative to liquid or compressed hydrogen tanks. Cryogenic vessels can virtually eliminate evaporative losses that typically occur in liquid hydrogen tanks, and they have an improved energy storage density compared to compressed hydrogen tanks. Research has shown that metal-lined composite pressure vessels can withstand cryogenic cycling with liquid hydrogen over an automotive lifecycle with no ill effects. A pickup truck with an onboard cryogenic pressure vessel has already been demonstrated.

LLNL researchers are also studying hydrogen adsorption in nanomaterials. Novel carbon-based materials, such as carbon nanotubes, activated carbon and carbon nanofibers, have received significant attention in this area. LLNL is investigating a new dimension of hydrogen storage research by combining nanostructured carbon materials and metal nanoparticles in a single hybrid material. The foundational components for the hybrid material are carbon aerogels, a unique class of mesoporous materials with many interesting properties such as low mass densities (0.02 to 0.5 g/cm^3), continuous porosities (up to 95 percent) and high surface areas (400 to 2,500 m^2/g). Fabrication is enabled by the development of the capability to incorporate uniform dispersions of metal nanoparticles into the aerogel framework. These metal-doped carbon aerogels (MDCAs) are ideally suited for hydrogen storage since these materials combine the high mass storage capacity of carbon aerogels with high surface-to-volume metal nanoparticles that can potentially influence and improve the energetics associated with hydrogen uptake and release (i.e., hydrogen spillover). Since the properties of the MDCAs can be systematically modified (e.g., amount/type of metal, porosity, surface area), it should be possible to design new materials that have enhanced hydrogen storage properties relative to the unloaded aerogels or the metals alone.

LLNL researchers are also addressing safety issues concerning hydrogen. A colorless and odorless gas, hydrogen, when mixed with air, is flammable in the range of 4 to 75 percent by volume concentration. This means that the potential accumulation of hydrogen fumes in or around hydrogen-powered vehicles must be monitored to ensure passenger safety. While all available information indicates that hydrogen will pose no greater safety risk than the use of natural gas or gasoline, the use of onboard hydrogen detection systems to address public safety concerns will likely be mandated. Hydrogen sensors with detection thresholds of 1 percent and response times of less than or equal to 1 second will be placed at strategic locations under vehicles and in passenger cabins.

LLNL researchers are developing a solid-state electrochemical hydrogen sensor that uses a ceramic oxide (yttria-stabilized zirconia, YSZ) electrolyte with two attached electrodes composed of tin-doped indium oxide (ITO) and platinum, respectively. This sensor has shown excellent sensitivity to hydrogen in the concentration range of 0.03 to 5.5 percent in air and has a response time of less than 1 second. It is little affected by the presence of other gases, including water, carbon dioxide and methane.

SNL researchers are also studying hydrogen storage but are approaching the problem from a very different perspective by storing hydrogen in hydride form. The two main classes of hydrides, metal and complex, achieve hydrogen storage and release through different mechanisms, each of which requires additional research before being sufficiently understood for incorporation into hydrogen systems.

SNL leads the Department of Energy's Metal Hydride Center of Excellence, a government/industry/university collaboration focused on developing a safe, economical hydrogen storage system based on reversible metal hydrides. Established in 2004, the center includes 16 other partners around the country (eight universities, three companies, and six national laboratories).

It is clear that complex hydrides, such as alanates, metal hydrides, and metal amides, can reversibly accept and release hydrogen, making them viable materials for hydrogen storage systems. However, before such systems can be designed, the engineering properties and physical behavior of the materials must be characterized in order to enable the optimization of gravimetric and volumetric storage densities and accurate thermal modeling. Properties such as thermal conductivity will dramatically influence the sodium alanate hydrogen-storage-bed design and its performance. SNL scientists and engineers are seeking a more detailed understanding of the chemical and physical processes governing hydrogen uptake and release in these novel solid materials. For example, by using optical diagnostics, such as infrared spectroscopy, in conjunction with mass spectrometry, SNL investigators have been able to probe the chemical bonding of hydrogen at the vapor-solid interface, as well as characterize the uptake and release kinetics that govern system behavior. The objective is to develop new hydrides that meet the DOE's FreedomCAR and Fuel Initiative storage goals.

Furthermore, SNL has partnered with General Motors Corporation (GM) to design and test an advanced hydrogen storage method based on sodium alanates. GM and SNL have embarked on a 4-year program to develop and test hydrogen storage tanks, with the goal of developing a pre-prototype solid-state tank that would store more hydrogen than current conventional hydrogen storage methods.

Even after the questions of production, supply, and distribution have been answered, the engines that currently burn hydrogen fuel are far from perfect. While the potential for hydrogen-fueled internal combustion engines to operate as clean and efficient power plants for automobiles is now well established, the unique combustion characteristics of hydrogen that allow clean and efficient operation at low loads present difficulties at high loads. The low ignition energies of hydrogen-air mixtures cause frequent unscheduled combustion events, and the high combustion temperatures of better mixtures lead to increased production of nitrous oxides (NOx). In addition, port-fuel-injected engines suffer from a loss in volumetric efficiency due to the displacement of intake air by the large volume of hydrogen in the intake mixture. All of these effects limit the power densities of conventional hydrogen engines.

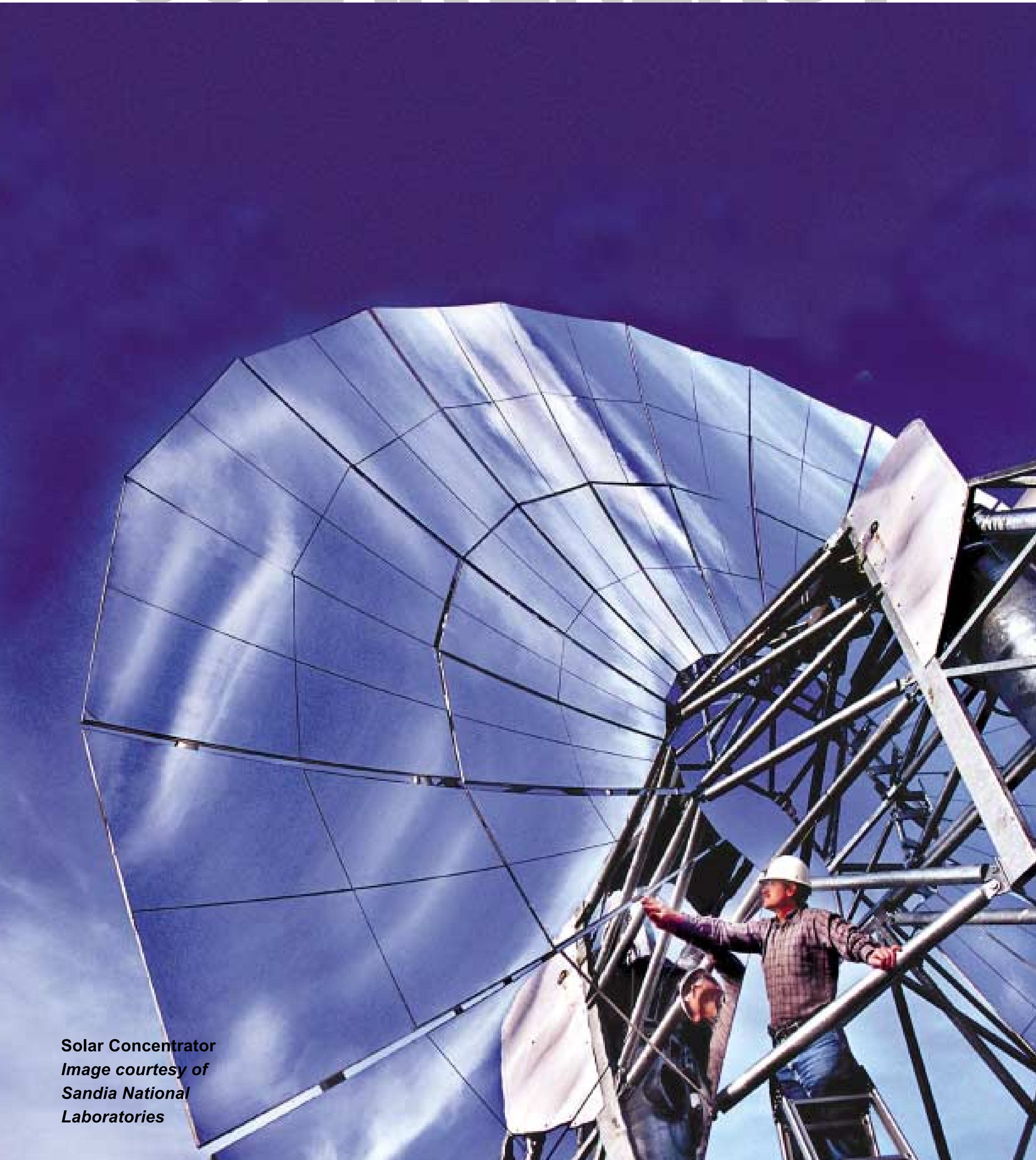
Therefore, SNL researchers are pursing the development of advanced hydrogen engines with improved efficiency and power density, as well as reduced NOx emission. In particular, the focus is on increasing the power density by direct in-cylinder injection of the hydrogen. The challenge with direct injection is that it requires hydrogen/air mixing in a very short time (approximately 4 ms at 5,000 rpm). Since mixture formation at the start of combustion is critical to engine performance and emissions, a fundamental understanding of the effects and optimization of in-cylinder hydrogen-air mixture formation is necessary before commercialization is possible.

None of the above will happen overnight. Hydrogen is likely to become part of the world's energy supply step by step, as technical challenges are overcome and market forces create new opportunities. It might take decades to transition to hydrogen-based energy and transport systems that are economically sound on a large scale.

In the meantime, there is plenty of work to do in getting from here to there. This is the transition phase—the era of "practical hydrogen"—a time for the industry to develop, test, and commercialize the best products and processes. This is a time for intensive research and development work, along with partnerships that demonstrate prototype fuel cell vehicles, infrastructure solutions, and specialized stationary-power applications. It is also the time for formulating critical national and international policies, codes, and standards for hydrogen.

In a white paper report entitled *An Integrated Hydrogen Vision for California*, prepared by UC Berkeley's Renewable and Appropriate Energy Laboratory, the authors concluded that "Hydrogen can fill an important role in our national energy policy by providing a means to store electricity, and to greatly expand the opportunities for zero-tailpipe-emission vehicles. But we also conclude, along with the National Research Council and many others, that significant scientific and engineering advances are needed for the transition to advance in a meaningful and sustainable fashion."

SOLAR ENERGY



Solar Concentrator
Image courtesy of Sandia National Laboratories

In terms of being renewable and carbon-neutral, there is no better source of energy than the sun. Travis Bradford, President and Founder of the Prometheus Institute for Sustainable Development, in his highly praised book, *The Solar Revolution*, calls the shift to solar energy inevitable, based on sheer economics: one day it will be the best and cheapest way to produce electricity and other forms of power. The copious availability of solar radiation in the San Francisco Bay Area makes the region an ideal test bed for solar energy production research and development. This fact has not been lost on BASIC member institutes that have conducted research on and implemented solar energy systems for consumers ranging from satellite companies, to community colleges, to residential homeowners. For example, SNL was chosen to be one of the major participants in the DOE's Solar Energy Technology Program (SETP), which is being funded in part under the federal government's new $148 million Solar America Initiative (SAI). The SAI is aimed at accelerating the development of advanced solar electric technologies, including photovoltaics and concentrating solar power systems, with the goal of making them cost-competitive with other forms of renewable electricity by 2015.

In terms of being renewable and carbon neutral, there's no better source of energy than the sun. Experts say that with improved photovoltaics and other technological advances, the shift to solar energy as a means of producing electricity and other forms of power is inevitable.

There are currently two primary techniques for harnessing solar energy for electricity production: 1) photovoltaic (PV) cells, and 2) solar thermal systems. Both techniques can be enhanced through the use of concentrating mirrors and/or heliostats, devices that track the movement of the sun and thereby minimize the size of the solar panels needed to produce electricity or usable thermal energy.

While PV cells have been in commercial use since 1955 when a Georgia telephone carrier used a solar cell developed at Bell Lab, the principal obstacle to large-scale usage has been the production costs of the cells themselves. For this reason, a major focus of research in the Bay Area has been to develop lower-cost production for PV cells. The Global Climate and Energy Project (GCEP) at Stanford University was initiated in 2002 with the support and participation of four international companies: ExxonMobil, General Electric, Schlumberger and Toyota. GCEP is scheduled to invest $225 million over 10 years to explore efficient and environmentally benign energy sources. One of the possible solutions is a more efficient PV cell consisting of semiconducting polymers. These cells will cost significantly less than current PV cells due to the fact that reel-to-reel coating machines similar to food packaging machines can be used to deposit the semiconductor onto the flexible polymer substrate. The result will be a low-energy, low-cost manufacturing process for lightweight and flexible PV cells with energy conversion efficiencies comparable to standard state-of-the-art PV manufacturing techniques. GCEP is also exploring additional means of developing low-cost and specialty PV cells, including thin-film solar cells fabricated from nanostructured materials and atomic layer deposition (ALD); nanostructured metal-organic composite solar cells that embed high-conductivity nanopatterned metal films in organic devices; and solar cells with an integrated matrix of silicon oxide films and silicon quantum dots that efficiently absorb energy along the entire solar spectrum. GCEP is also exploring the possibility of using green algae (specifically *C. reinhardtii*) and their photosynthetic cells instead of silicon-based PV cells as a mechanism of solar energy capture.

A number of private companies in the Bay Area have already turned advanced research in high efficiency, low-cost solar cell manufacturing technology into viable business models. SunPower in Sunnyvale, a subsidiary of Cypress Semiconductor, is a highly successful low-cost manufacturer of high efficiency single-crystal solar cells. Based on technology pioneered by former Stanford Electrical Engineering professor Dr. Richard Swanson, SunPower's solar cell is unique in that the metal contacts that are needed to collect and conduct electricity are on the back surface of the solar cell, thus maximizing the surface exposure of the solar cell and improving solar-to-electricity efficiency rates. Not incidentally, the resulting uniformly black surface area is also more popular with design-oriented businesses and consumers. SunPower's solar cells were used to power NASA's Helios solar-powered airplane for a world record power-flight altitude of 96,863 feet. And at 21.5 percent, SunPower boasts the highest efficiency commercially available solar cells for land-based use.

More than two decades of research by the DOE's national labs and the Department of Defense have made the prospects for a high efficiency (greater than 15 percent) thin film copper-indium-gallium-diselenide (CIGS) cell look very promising. If the production costs can be reduced significantly, CIGS-based photovoltaic cells will begin to play an important role in power production.

Miasolé is a Bay Area startup company focused on manufacturing thin-film solar cells. Under the leadership of David Pearce and Dennis Hollars, the company is combining DOE's 25 years of research in thin-film solar cell materials with Pearce and Hollars' 20 years of high volume thin-film production and semiconductor design experience to develop an in-line sputtering system for manufacturing CIGS solar cells on stainless steel foil with a 10 percent conversion efficiency. Miasolé's production system utilizes stainless steel foil substrates and a roll-to-roll process that allows for the production of an "all sputtered" CIGS solar cell in which each layer of the cell is deposited in a single pass through a single vacuum system, greatly increasing throughput and reducing costs. Stainless steel enters the vacuum system and fully coated solar cell material exits. The entire operation takes less than an hour and does not require additional lighting, leading to cost-effective manufacturing. Plans are afoot for a new manufacturing facility in Santa Clara, which will eventually have the capacity to produce 200-megawatt systems.

The semiconductor layers of a CIGS solar cell are less than 1/100th the thickness of silicon in a conventional crystalline silicon solar cell. Because Miasolé's production process is also less capital intensive and requires a single deposition of the silicon compound, the process is less labor-intensive and has lower overhead costs. The company's goal is to reduce the cost of solar installations by 75 percent over crystalline silicon. That would make solar installations potentially competitive with conventional sources of electricity.

Nanosys, Inc. in Palo Alto is another Bay Area startup company that is using innovative techniques to produce solar cells. By combining thin-film electronics technology and high performance inorganic nanostructures, Nanosys can produce a new type of solar cell that performs like a traditional solar cell but can be configured like a lightweight flexible plastic. This hybrid technology, which was pioneered at Berkeley Lab, has the potential to provide low cost solar power through currently available, high volume and inexpensive manufacturing techniques based on conventional thin-film processes.

Other Bay Area companies are pursuing alternative ways to harvest solar energy. For example, solar thermal systems use sunlight to heat a working fluid such as water or oil. When combined with reflective materials to concentrate the sun's heat energy, these systems can produce steam to drive a generator to produce electricity. Solar thermal systems include dish/engine systems, parabolic troughs, and central power towers. Such systems have been in use in California since the Carter administration established tax incentives in the late 1970s. Since then, the technology has improved and its cost has decreased by at least 50 to 70 percent. Low-temperature solar collectors now absorb the sun's heat energy for hot water or space heating in residential, commercial and industrial facilities.

Solar concentrator systems, whether PV (photovoltaic) concentrator or solar thermal electric systems, all rely on the same basic technique in which light is concentrated to a central receiver using mirrors or refractive optics. Solar concentrators require direct solar illumination, and the optics or mirrors must move during the course of the day to track the sun's trajectory. A key benefit of concentrator devices is that they make it possible to reduce the physical size of the receiver relative to the area in which the light is gathered. The area over which light is gathered for a given type of receiver ranges from a few centimeters for some PV concentrators, to meters or tens of meters for Stirling engines, to hundreds of meters for solar thermal electric systems.

Currently available solar concentrator technologies cost $2 to $3 per watt, which results in a solar power cost of 9¢ to 12¢ per kilowatt-hour. New innovative hybrid systems that combine large concentrating solar power plants with conventional natural gas combined cycle or coal plants can reduce costs to $1.50 per watt and drive the cost of solar power to below 8¢ per kilowatt hour. Advancements in the technology and the use of low-cost thermal storage will allow future concentrating solar power plants to operate for more hours during the day and shift solar power generation to evening hours. Future advances are expected to allow solar power to be generated for 4¢ to 5¢ per kilowatt-hour in the next few decades, which would make it economically competitive with conventional electricity generation technology costs.

BASIC member Lockheed Martin is conducting promising research in using its solar concentrator technology for terrestrial power. This technology was originally developed for satellites by GA Technologies, which successfully demonstrated solar thermionic converters with a 16 percent conversion efficiency in a ground test at NASA's Marshall Space Flight Center. If the Lockheed Martin/GA technology were to be applied to terrestrial power production in conjunction with recently developed 25 percent efficient thermoPV cells, it theoretically could achieve a greater than 40 percent conversion efficiency as a thermal bottoming cycle. This is much higher than any current terrestrial PV converters. It is the contention of Lockheed Martin researchers that these solar concentrators could be integrated with gas heaters to provide the necessary heat source during the night.

The Electric Power Research Institute (EPRI) in Palo Alto, together with Southern California Edison, has been at the forefront of large-scale demonstrations of solar thermal electric systems for the past two decades. The Solar One project in the Mojave Desert concentrated light from 1,800 moving mirrors (heliostats) onto a tower and used this collected energy to generate steam and power a turbine. In tests, the system generated an impressive 10 megawatts of power. A second generation system, in which the heat transfer material is molten salt instead of steam, has been built on the same site.

Compared to solar thermal concentrator systems, concentrator PV systems have historically had limited success, suffering from reliability issues, and gaining less than 1 percent of the market for solar electric generation. However, since 1995 a number of concentrator PV installations on the 10 to 100 kilowatt scale have provided sufficient data to build confidence in the technology. With concentrator PV systems projected to achieve $3 per watt in the next few years, Bay Area companies and research institutions are well positioned to lead, both in technology innovation and in commercial applications.

A number of companies are already building concentrator devices that may be suitable for commercial rooftops, and possibly even residential settings. Researchers with H2GO, a startup company in Saratoga, CA, and UC Merced have collaborated on a novel solar concentrator design that uses tailored imaging with a primary and secondary mirror, plus a tapered glass rod to achieve a net flux concentration of 500 suns. The hexagon devices can be tiled together to make panels on the order of 1 to 2 meters in size.

For the development of a second-generation device, PARC, a subsidiary of Xerox Corporation that conducts interdisciplinary research in physical, computational, biomedical and social sciences, joined forces with SolFocus, a Palo Alto-based company that specializes in low-cost solar panel products. The first-generation design for a low-cost photovoltaic module at SolFocus was honored with the grand prize at the recent National Renewable Energy Laboratory's 18th Industry Growth Forum. A second-generation version of this device uses a very thin, solid optic to provide the primary and secondary reflective surfaces. Micro-concentrators are molded into a single glass sheet, and the highest efficiency cells from Spectrolab (the world's leading manufacturer of solar cells and panels) are placed on the back of the glass using high speed pick-and-place equipment. Because of their thin construction and low weight, these devices will be suitable for commercial rooftop installation and may become commercially competitive with flat panel PV cells, provided a reliable method is developed to maintain a clean environment and a constant orientation towards the sun.

While a number of Bay Area research institutions and companies are continuing to pursue more efficient and lower-cost photovoltaic solutions, Chevron Energy Solutions (CES), a wholly-owned subsidiary of Chevron that develops, engineers and installs energy efficient facility upgrades for public institutions and businesses, is currently implementing solar energy systems for major energy consumers. One notable example of this has been CES's work with the U.S. Postal Service to optimize efficiency and conserve energy resources in Northern California. In 2004, CES completed improvements at the Postal Service's West Sacramento Processing and Distribution Center, which included the nation's largest nonmilitary federal solar power installation. The improvements are expected to reduce the facility's annual power consumption by more than 33 percent, or about 5.5 million kilowatt-hours per year, and will reduce natural gas use by about 43,000 therms per year. CES is also under contract with the Postal Service to develop, engineer and install energy efficiency upgrades and renewable power generation systems at other mail processing facilities throughout Northern California. In addition to facilities in West Sacramento and San Francisco, CES is upgrading dozens of facilities (average size 132,000 square feet) in Oakland, San Jose, Stockton, Marysville, Vacaville, Livermore, Berkeley and Salinas. Future phases are in progress to expand this program to 100 more facilities in the next few years.

Bay Area community colleges—another significant energy consumer—have also asked CES to develop and install both energy efficient and renewable power systems. For the Foothill-De Anza Community College District, for example, CES completed in 2005 the installation of more than 780 kilowatts of solar electric and energy-efficient cogeneration projects at both the Foothill and De Anza campuses, including a heliostat. Along with prior improvements to lighting, air conditioning and energy management systems, the installations will reduce the district's electricity purchases by 46 percent—which is more than 11 million kilowatt-hours annually—and save the district about $800,000 a year.

Solar energy, of course, is already used widely throughout the world by green plants. Through photosynthesis, green plants are able to harvest sunlight and convert it into chemical energy at a transfer efficiency rate of approximately 97 percent. Researchers at Berkeley Lab are seeking to understand how photosynthesis works at the molecular and electronic levels. If this can be accomplished, it should then be possible to create artificial versions of photosynthesis. Working out of some of the same facilities where Melvin Calvin once mapped the chemical pathway of carbon in photosynthesis (for which he won the 1961 Nobel Prize in Chemistry), and using a combination of a new probing technique called two-dimensional electronic spectroscopy, which can measure molecular energy transfers on a femtosecond timescale (a femtosecond is a millionth of a billionth of one second), and the supercomputational capabilities of DOE's National Energy Research Scientific Computing Center (NERSC), the researchers have to date identified several key energy donor and acceptor molecules. They have also identified the molecules that help protect plants from oxidation damage as the result of absorbing too much light.

In his book, *Solar Revolution*, Bradford states: "Although the size of the existing energy infrastructure and the long life of the assets employed may mean that it will be many years before the world is dominated by clean, virtually unlimited solar energy, the increasing momentum in that direction will transform the world and our expectations long before."

WIND ENERGY

WIND ENERGY

Wind Turbine
Image copyright Wolfgang Amri, Amri Design; used with permission

Chapter Six: Wind Energy

The power of the wind has been used for centuries for milling and pumping, but it was not until the late nineteenth century that Charles F. Brush, an inventor and manufacturer of electrical equipment, designed and built the first 12 kilowatt windmill for the generation of electricity. Another century of development in aerodynamic, electrical, materials, mechanical, and structural science and engineering has transformed the massive Brush windmill with its multi-blade rotor into the sleek three-bladed, multi-megawatt wind turbines that are presently found around the world.

Starting with the creation of wind farms or wind plants in California in the 1980s, worldwide installed wind power capacity has grown rapidly to 59.3 gigawatts at the end of 2005. In 2006, the installation of new wind-based electricity generation equipment in the U.S. was expected to exceed 3,000 megawatts. This growth is fueled by the fact that wind is abundantly available in many regions around the world. Wind energy conversion systems do not generate air pollution, and their cost is competitive with that of fossil fuel power plants and is immune to volatility in fuel prices. Furthermore, a wind plant consisting of multiple wind turbines can be installed, connected to the grid, and start generating electricity within a year, making it one of the more rapidly deployable power generation technologies.

Wind energy conversion systems are pollution-free, cost-competitive with fossil fuel power plants and immune to volatility in fuel prices. California leads the nation in wind power capacity, generating electricity for more than half a million homes.

In the United States, California is the leader in terms of installed wind power capacity. California's wind plants generate electricity for more than 530,000 homes. Since the "wind rush" of the early 1980's, wind energy in California has started a second renaissance, driven by matured technology, lower production costs, and California's Renewables Portfolio Standard (RPS). Over the past 20 to 25 years, economic drivers have refined utility-scale wind turbine designs into low-cost, reliable, megawatt-sized machines. These large wind turbines currently have a cost of electricity (COE) which ranges from $0.04 to $0.06 per kilowatt-hour. The goal is to drive the cost down to $0.03 per kilowatt-hour to make wind energy more competitive with the COE of conventional fossil fuel power plants.

In support of state RPS policy and wind energy development efforts, a number of Bay Area institutions and companies are looking at innovative technical and market solutions to address regional, national and international renewable energy issues. Solutions span a broad range that includes technological advances in design, transmission infrastructure analysis, market planning, and environmental monitoring.

BASIC members UC Davis and LLNL have developed wind turbine blade technologies that would decrease the COE of wind turbines by increasing the energy capture for any given blade weight. These technologies include blunt trailing edge airfoils for the inboard portion of large blades and an aerodynamic load control system based on actively controlled microtabs, which are retractable and controllable devices for the outboard portion of large blades. The technology can potentially reduce wind-loading on turbine blades, reduce the stress transmitted to components, and increase turbine life while reducing system weight and costs.

“These devices also have the potential to reduce load on wind turbines, decrease the wake generated by airplanes and reduce noise made by helicopters,” said LLNL researcher Dora Yen-Nakafuji, co-inventor of the technology. “We’re looking at wind turbine systems to provide the first test platform for testing the microtabs.”

Computational and experimental research projects are continuing, but preliminary results are promising and have already piqued the interest of wind turbine manufacturers.

While engineering improvements have provided the capability for economical wind power expansion, California’s RPS provides political impetus. The RPS, adopted in 2003, requires that 20 percent of the state’s energy consumption be met by renewable energy sources by 2017. With this legislative requirement, state agencies such as the California Energy Commission (CEC) and the California Public Utilities Commission (CPUC) have committed to large-scale adoption of renewables in the short term. Because of its mature state, wind power, along with geothermal, is expected to fulfill the majority of California’s RPS requirement.

One of the remaining technical issues posed by the energy generated by wind plants is the fact that wind, like solar, is heavily weather-dependent and cannot be perfectly controlled or predicted. Thus, the peak winds during a twenty-four-hour period often do not match consumers’ peak electrical demand, which may pose difficulties with the integration of wind-generated electricity into the power grid. However, in a study conducted by the CEC and the California Wind Energy Collaborative (CWEC) at UC Davis, in collaboration with the National Renewable Energy Laboratory and Oak Ridge National Laboratory, it was found that the inherent variability of certain types of renewable energy sources, including wind, had little effect on the dependability of the electrical grid at the current level of renewable energy usage. This indicates that wind energy and other intermittent renewables can be successfully integrated into the electrical system. A detailed analysis is currently underway to model the operational specifics of integrating even higher penetration levels of wind power in

California. This extensive effort involves the CEC, the CWEC, GE Energy, Davis Power Consulting in San Jose, and BEW Engineering in San Ramon.

Researchers at LLNL have teamed up with avian experts, consultants and the CEC to develop a web-based decision aid for tracking, evaluating and integrating wind information relevant to resource planning and repowering. Leveraging LLNL's remote sensing data and analysis capability, the Renewable Portal is intended to provide researchers, policy makers and planners a one-stop shop to access geographically consistent renewable data and the latest development trends with the added capability to perform trade-off analysis. The initial portal demonstrates analysis capability for wind energy, however the portal will be upgraded in the future to include other renewable resources, such as solar, geothermal, biomass and hydro, plus climate impact data and other modeling layers.

LLNL's Energy and Environment Directorate (E&ED) is home to a national and international atmospheric, earth, environmental, and energy science modeling knowledge base, which has been charting the nation's energy production and use since 1975. LLNL's U.S. energy flow charts, based on projections by DOE's Energy Information Administration (EIA), the CEC and other data sources, track energy trends, supplies and demand in electrical generation, residential and commercial heating, and industrial and transportation uses. The charts were recently automated to illustrate the implications of various "what-if" scenarios of energy supply, efficiency and demand.

Researchers at LLNL have teamed with the state, universities and industry to apply their complex atmospheric models, remote sensing and GIS analysis capability and energy modeling to help the wind industry by improving wind energy forecasting, addressing wind plant location issues, and studying intermittency impact on the future grid.

An example of technologies that can help alleviate intermittency due to wind generation is the "megawatt in a box" test project at PG&E's Distributed Utility Integration Test (DUIT) facility in San Ramon, California. PG&E, the CEC's Public Interest Energy Research (PIER) Program, the California Independent System Operator (CAISO), in conjunction with the DOE and Beacon Power Corporation, are testing a first-of-its-kind energy storage technology that can increase reliability and control on the grid. This new technology consists of a series of large, high-speed flywheels that can store excess energy from the grid. Whenever the grid needs more energy to stay in balance, a signal is sent and the flywheels convert into generators to add power cleanly and efficiently.

Wind energy forecasting is another technology that will reduce intermittency impact due to the "on-off" nature of wind. Like forecasting the weather, wind energy forecasting provides utility planners and schedulers with short-term (hourly resolution) and long-term (day ahead) look-aheads on wind generation resources. Planners and schedulers are responsible for running the electricity grid and keeping the demand and supply for energy balanced. The wind resource is inherently uncontrollable, but there are seasonal trends, daily trends and weather parameters that can be monitored to forecast when the wind will blow. Based on recent wind energy research, accurate weather forecasting and terrain modeling have been recognized as important factors to further improve the wind energy forecast for effective power management. In a multi-year project, the Electric Power Research Institute (EPRI), the CEC, UC Davis, LLNL, CAISO, and various utilities and wind power generators throughout the state have been involved in a cooperative research project to develop, improve and implement wind energy forecasting tools. Researchers at LLNL are able to provide higher resolution, site specific weather forecasts to help investigate sources of wind energy forecasting errors, validate the accuracy of forecasting and help improve confidence in the technology. The availability of accurate wind energy forecasting models for both next-hour and next-day and longer forecasts will make it possible to anticipate wind speed and generation fluctuations by time of day and season and to better plan and manage operation of an electricity system with major wind energy components.

While UC Davis, LLNL, and other research institutions are developing the technology and the infrastructure for the wind to be tapped as a viable source of electricity, the Sacramento Municipal Utility District (SMUD) is operating wind turbines located in the Montezuma Hills in Solano County, which generate enough electricity to supply approximately 3,500 single-family homes. The utility owns 3,300 acres in Solano County and first installed wind generation on the property in 1994. Precise locations for each turbine were selected based on several years of wind data and topographical maps. As a result, the turbines are strategically placed to take full advantage of the winds that whip in from the California coast, race through the Carquinez Straits, and spill into the Sacramento and American River Delta region, which is one of the best locations in all of California for wind generation.

Given the current state of technology and rising demand, in the next three to five years, the wind industry is predicted to continue growing at an exponential rate worldwide. Developing nations, including India and China, will be electrified by wind, and globally, wind energy will also play a vital role in supporting and expanding international policy options required to tackle global warming. Important global research, such as that carried out by BASIC members like UC Davis and LLNL, will continue to shed light on the issue of climate change and the impact of carbon dioxide emissions while helping to make the wind resource a viable source of renewable energy.

“It is an enormous undertaking to address the challenges in national security and to effect change in environmental management and energy supply. However, the Laboratory excels at addressing these national needs,” said LLNL’s Jane Long, Associate Director for the Energy and Environment Directorate.

NUCLEAR ENERGY

Nuclear Power Plant
Image courtesy of the National Renewable Energy Laboratory

Given that many of the alternative energy sources discussed in the previous chapters of this publication could be years away from commercial viability, there is a need to reexamine the possibilities of nuclear power. There are two forms of nuclear energy: fission, in which atomic nuclei are split to release thermal energy; and fusion, in which a pair of lighter atomic nuclei are fused together to form a single heavier nucleus, releasing even greater amounts of thermal energy. The use of fission energy is already a commercial reality, whereas fusion energy remains an elusive dream. BASIC member institutes have research programs aimed at improving the former and developing the latter.

Even in the United States, the use of fission nuclear energy remains widespread, with about 20 percent of all electrical power production coming from the nation's 103 operating reactors. However, all of the current domestic reactors are relatively old, and no new ones have been started in more than two decades. One of the principal reasons for this hiatus in the U.S. is that the cost of electricity from new nuclear plants had been noncompetitive with other electricity sources, a situation which has changed due to the recent changes in the oil markets. Other reasons include high startup costs and the lack of a permanent repository for nuclear waste disposal.

The use of fission nuclear energy accounts for about 20 percent of all the electrical power produced in the United States. With nuclear power becoming increasingly competitive as a source of electricity plus significant technological advances including improved safety, nuclear fission could play a major role in meeting future domestic energy needs.

In a 2005 report funded by the Organisation for Economic Co-operation and Development (OECD), the Nuclear Energy Agency and the International Atomic Energy Agency, it was stated that nuclear power had increased its competitiveness over the past few years. Furthermore, the U.S. nuclear power industry has not been stagnant in the interim. First, the existing plants are running significantly better than they were twenty years ago, to the extent that the U.S. reactor fleet is producing about one-third more electricity annually than it did early on. This is largely due to improvements in capacity factors: the plants run more reliably, shut down less often, and refueling outages take less than half as long as they once did. Safety performance has also improved dramatically, with major improvements in every one of the main safety indicators. The security of the plants against sabotage or other malevolent acts has always been very strong, and is stronger still after recent upgrades in response to the September 2001 attacks in New York and Washington. Despite the absence of new construction, the U.S. nuclear electricity industry has remained dynamic.

Today in the U.S., for the first time since the long hiatus began in the late 1970s, a resurgence of interest in ordering new reactor plants is being expressed by domestic electric utilities. Several utility companies or utility consortia have announced tentative plans to build new reactors using evolutionary new designs that build on the experience and lessons learned from plants already operating around the world. Already several sites have been tentatively selected for the new reactors, and these sites are now being examined by the Nuclear Regulatory Commission (NRC) for possible approval. Finally, recent Congressional legislation (the Energy Policy Act of 2005) provides financial incentives and subsidies as a means of stimulating the first orders for several new reactors. However, in the U.S., if fission nuclear power is to be a successful technology in the future, the domestic nuclear industry, and the supporting government laboratories and university researchers face five major challenges.

First, the U.S. must continue to operate the existing fleet of over 100 reactors safely, securely, and economically over their remaining lifetimes. Second, the U.S. must begin soon to build new reactors using "evolutionary designs," so as to expand nuclear energy's role within the next decade or so. Third, the country must begin working to develop the more advanced reactor and fuel-cycle systems of the future, so that in a couple of decades these systems will be available in the marketplace for deployment. Fourth, the advanced technologies to be developed need to embed as many advanced security and nonproliferation features as feasible, so that worldwide expansion of nuclear power can be accomplished in a way that does not threaten security. And finally, the development of the deep-geological repository at Yucca Mountain, Nevada must continue to proceed toward an orderly opening date, after having received regulatory approval from the NRC, so that the disposal of the radioactive waste will no longer be seen as a barrier to continued nuclear power development.

BASIC members LLNL, UC Berkeley and Stanford University have decades of experience in fission nuclear power research and development, and Bay Area companies have continued to be the leaders in this industry since the inception of commercial nuclear power almost fifty years ago. These and other Bay Area institutes are helping to address each of these five challenges.

PG&E operates a two-reactor station at Diablo Canyon, which lies west of San Luis Obispo. The Diablo Canyon power plant has long been among the leading performers in the U.S. in terms of both safety and economical operation. This performance is supported by a large number of firms in California, many in the Bay Area, who provide engineering services. Many of these firms are small, although a few, such as Bechtel, are very large. Indeed, the Bay Area hosts a number of smaller firms, centered in San Jose, Berkeley, Walnut Creek, Livermore, Palo Alto and San Francisco, that support all 103 of the country's operating nuclear units with equipment, analysis, manpower, supplies, and radioactive waste services. The operating reactors continue to advance technically, employing better control systems, better operator training, better parts-replacement management, and other improvements that often involve very high-tech advances supported by Bay Area firms.

Many of the major technological advances that are incorporated in the new "evolutionary designs" emerged from the Bay Area, including advanced control systems, metallurgical advances, and improved seismic designs. The General Electric Company operates its

Nuclear Energy Division in San Jose, which has a Boiling Water Reactor (BWR) simulator facility, and a spent-fuel hot-cell lab at the Vallecito Nuclear site is less than 150 miles away from San Jose. Both GE and the Electric Power Research Institute (EPRI) in Palo Alto have for a long time been major forces in designing evolutionary technological advances. In fact, EPRI's Nuclear Program serves as a partner to the global nuclear industry, enabling plant operators and engineers worldwide to improve station performance and availability while they address the growing challenges of equipment obsolescence, staff reductions, and resource constraints. At the core of EPRI's nuclear power research effort is a collaborative, multidisciplinary approach to problem solving, which combines incremental design improvements to critical equipment. The overall EPRI Nuclear Program reflects the need to maintain safety, while operating and maintaining the current base of nuclear power plants for as long as practical. LLNL has supported NRC activities as it performed the technical reviews necessary to certify the new designs and as it has begun the process for approving the newly proposed sites.

The development of advanced design concepts has been, in a major way, the special province of the DOE, and in the Bay Area that work is concentrated at LLNL, collaborating with the UC Berkeley campus and three other DOE national laboratories around the country. Although several advanced concepts are under development at other locations, the work here has centered around a novel advanced reactor concept involving a fast-spectrum lead-bismuth cooled reactor. The design concept, which is called the Small Sealed Transportable Autonomous Reactor (SSTAR), is small enough that the reactor could be manufactured in a factory and barge-transported to a remote site, where it would run for two decades without the need for refueling. The design has advanced security features, a very safe configuration, and minimal radioactive waste.

Another LLNL effort has involved supporting the DOE initiative to develop advanced fuel-cycle technologies that would reprocess spent fuel and recycle the useful remaining fuel and some of the more hazardous radionuclides back into specially designed reactors for destruction. The objective of this approach is to substantially decrease the radioactive waste stream from nuclear power, thereby easing the need for a large number of deep-geological repositories. LLNL has worked on materials problems, advanced fuel technologies, reactor system design, safeguard and security issues, repository technology, and several other high-technology issues.

Lockheed Martin in Sunnyvale, California, has also contributed to technological advances, with a particular focus on Space Nuclear Power for deep-space probe launch safety analysis, small isotope-powered devices for nonspecified military applications, and nuclear power system concept developments for space exploration and Mars settlement applications. Lockheed Martin Space Systems Company owns all existing software, technical know-how and documentation on the liquid metal-based fast reactor for space applications. SNL, which is operated by Lockheed Martin, has been a long-time national leader in

R&D for a wide variety of nuclear energy and risk management technologies. Working through both the DOE and the NRC, SNL researchers have pioneered studies in nuclear energy safety, new reactor designs, radiation environment testing, medical isotopes, and risk and reliability assessments. SNL is also the lead laboratory in the Global Nuclear Materials Management Initiative, although this work is conducted at SNL's facilities in Albuquerque, New Mexico.

UC Berkeley's Nuclear Engineering Department is one of the few nuclear engineering departments in the nation that has both graduate and undergraduate programs to educate students in nuclear engineering technology. Its curriculum focuses mainly on spent fuel waste management and fusion nuclear energy technology. This program and its approximately 100 students position the University, as well as the Bay Area, to be the major sources of any future nuclear power workforce.

The issue of security and nonproliferation has been a major concern of several Bay Area institutions for a long time. For decades, faculty at both Stanford and UC Berkeley have been leading participants in U.S. and international nonproliferation policy development. LLNL has always played a major role in developing advanced technologies that impede proliferation and allow inspectors to detect proliferation if it were to occur, and in supporting broader U.S. nonproliferation policy in many different ways, some of which are classified for national security reasons. LLNL researchers also work on advanced technologies that can improve overall national security while allowing nuclear power to advance.

In 1978, the DOE began studying Yucca Mountain, which is located in a remote desert on federally protected land approximately 100 miles northwest of Las Vegas, to determine whether it would be suitable for the nation's first long-term geologic repository for spent nuclear fuel and high-level radioactive waste. The repository must be able to isolate the waste for at least 10,000 years—a time span equivalent to before construction of the Egyptian pyramids until the year 5,000 AD. The Bechtel Corporation has an important role as the prime contractor working in Nevada to develop this proposed repository. Both LLNL and Berkeley Lab have been major contributors for the past two decades in developing the underlying scientific knowledge needed to design the Yucca Mountain repository and to assure that it will meet all applicable safety regulations.

One of LLNL's long-standing activities has been the development of methods that enable analyses of the underground environment. LLNL has also been performing tests to understand water flow and radionuclide transport; studying the potential for corrosion of the canisters that will contain the waste underground; helping to determine how the waste can be transported from elsewhere in the U.S. to the repository safely and securely; and developing advanced materials. Berkley Lab researchers have developed a three-dimensional site scale model for characterizing hydrogeologic conditions inside the mountain under a wide range of different scenarios. They have also developed a hydrological model that accurately calculates seepage into waste emplacement tunnels under various hydrogeologic conditions.

The involvement of Bay Area research institutes in the further development of fission nuclear power is likely to continue into the future, as the DOE is planning a major new advanced reactor system development effort. Bay Area institutes are also expected to play major roles in the policy analyses and deliberations that will support the national and international political efforts to prevent nuclear weapon proliferation while allowing for expanded use of fission nuclear power.

There is a joke that says, “Fusion is the energy source of the future…and always will be.” That this joke has been around for more than two decades illustrates the difficulty of the technical challenges that fusion, as a source of commercial energy, presents. And yet the allure of fusion energy remains powerful. A typical fusion reaction releases roughly one million times the energy released by the burning of oil. Fusion fuel consists of deuterium and tritium, the two isotopes of hydrogen. Both can be obtained from sea water—deuterium is extracted directly through hydrolysis, and tritium is bred from the element lithium, which is also abundant in the earth’s crust. Enough fusion water to supply a year’s worth of electrical power to a city like San Francisco could be delivered in a pickup truck. As an energy source, fusion would last forever, and it would not contribute to greenhouse gases or global warming. Furthermore, unlike nuclear fission, fusion cannot sustain an uncontrolled chain reaction, nor does it generate high-level radioactive waste. However, learning to initiate and control a sustained fusion reaction has proven to be most formidable.

In 1999, after decades of individual institutional efforts, Berkeley Lab and LLNL combined with the Princeton Plasma Physics Laboratory (PPPL) to form the U.S. Heavy-Ion Fusion Virtual National Laboratory (HIF-VNL). This collaboration is dedicated to the development of heavy-ion accelerators capable of creating a fusion reaction by imploding tiny capsules of nuclear fuel. While heavy-ion fusion (HIF) hasn’t received the public attention given to magnetic fusion energy (MFE)—the tokomak-based concept behind the International Thermonuclear Experimental Reactor (ITER)—HIF-VNL researchers have continued to make steady progress. In an HIF reactor, an imploded pea-sized capsule of nuclear fuel burns quickly enough to keep it confined by its own inertia. This confinement lasts long enough for the reaction to produce energy. The implosion that ignites the fuel is set off or “driven” by high-powered beams of heavy ions, such as xenon, mercury or cesium, which are focused on the capsule. Major experiments are now being planned to develop and test ideas for accelerating, transporting and focusing beams of heavy ions on a target. This would culminate in an Integrated Beam Experiment (IBX). In the meantime, fusion targeting research will be carried out at LLNL’s National Ignition Facility (NIF), using the world’s largest and most powerful laser system.

ENERGY EFFICIENCY

ENERGY EFFICIENCY

Earth
Image courtesy of NASA

Chapter Eight: Energy Efficiency

It has been widely acknowledged by experts that efficiency is still the cheapest, fastest and most economically rewarding way of forestalling the energy crisis. While energy efficiency technologies alone cannot stem the rise in demand for more energy—global population increases ensure that demands will continue to escalate—they can help relieve the pressure and give alternative supply-side technologies more time to develop. At the same time, energy-efficient technologies can also reduce further exacerbation of global warming.

For example, a refrigerator that keeps food cold using 500 kilowatt-hours per year is cheaper to operate and far more desirable than one of the same size and features that uses 1,600 kilowatt-hours per year. Thanks to an extraordinary partnership of research institutions, government agencies, and private sector manufacturers, today we are in a situation where the latest refrigerators are three times as energy efficient as those of the mid 1970s.

Energy-efficient end-use technologies, systems and materials boast far-reaching benefits for the economy. If every gadget, house, office, factory and vehicle operates more efficiently, the result will be less money spent on energy and less use of natural resources.

Energy-efficient end-use technologies, systems and materials boast far-reaching benefits for the economy, because if every gadget, house, office, factory and vehicle operates more efficiently, the result will be less money spent on energy and less use of natural resources. Efficient technologies often also offer the advantages of lower maintenance costs, increased comfort for users/inhabitants, longer product lifetime, and lower overall life-cycle costs. They are also often safer to use.

The San Francisco Bay Area has been a leader in developing energy-efficient end-use technologies—and in conducting end-use energy analysis—since the 1970s, predating the first oil price shocks of that era. The effort started when researchers at Berkeley Lab began developing an ambitious building energy use simulation program, called DOE-2, to help engineers design more efficient buildings. Shortly after, scientists there founded a research program on energy efficiency that has grown into one of the nation's largest and most successful.

Bay Area universities have also been leaders in promoting energy efficiency. UC Berkeley began a graduate program offering degrees in energy and resources studies in 1973. Scientists at Stanford University began interdisciplinary research programs, such as Stanford's Energy Modeling Forum, to better understand the interactions of the economy, energy use, and the environment. Influenced by this activity, established companies and technology startups in the Bay Area and beyond began working with these institutions to develop energy-efficient lighting, window, and information technologies that are widely used today.

The Electric Power Research Institute (EPRI) has been another significant source of energy innovation. The Institute manages a portfolio of research in all areas of electric utility interest, funded by electric utilities throughout the nation at more than $270 million per year. A network of 2,200 advisors throughout the U.S. helps guide its work. EPRI's research portfolio includes managing some projects in the Bay Area, but much of its work is conducted by researchers throughout the U.S.

These first waves of efficient end-use technologies have evolved from the world of research and development and are now in the marketplace. Technologies developed by Bay Area researchers and companies include: low-emissivity windows, which help buildings retain heat in the winter and keep out solar heat-gain in the summer; efficient electronic ballasts for fluorescent lighting; software for energy efficient building design; and efficient integrated circuits for DC power supplies, computers and consumer appliances.

Despite the progress of the last 30 years, many energy experts believe that there is still considerable room to improve efficiency, both from motivating the adoption of existing efficient technologies and practices, and from developing new ones. The American Council for an Energy-Efficient Economy recently analyzed 11 studies of the potential for energy efficiency in various U.S. regions, and concluded that there is still a median achievable potential reduction of 24 percent for electricity use and 9 percent for natural gas. Another study, conducted by five DOE national laboratories in 1997, examined the potential of energy efficiency to reduce carbon emissions and found potential for reduction measuring hundreds of millions of tons of carbon per year, depending on how vigorously policies to adopt efficient technologies were pursued.

Now, the Bay Area's public and private sector researchers are rising to the challenge of developing the next generation technologies that will further reduce energy use and polluting fossil fuel and greenhouse gas emissions. The considerable progress in integrated circuits, information technology, miniaturized communications devices and sensors, and networks including the Internet and the Web is being followed by the application of these technologies to monitoring and controlling energy use in real time in almost any application imaginable. If the billions of energy-using devices on the planet can be controlled to use only the energy they need to fulfill their functions, and to turn themselves off or go into a lower power mode at appropriate times, then the energy savings could add up to hundreds of billions of kilowatt-hours per year.

The Center for Information Technology Research in the Interest of Society (CITRIS) is a leading Bay Area institution in this field. Located at UC Berkeley, CITRIS conducts research on highly-distributed, reliable, and secure information systems that can evolve and adapt to radical changes in their environments. Called societal-scale information systems, these technologies are being applied to energy, education, disaster recovery, transportation efficiency, diagnosis and treatment of disease, and economic growth. The CITRIS partnership also includes UC Davis, UC Merced and UC Santa Cruz, plus a network of corporate partners and affiliates.

Collaboration between Berkeley Lab, a Los Angeles-based lighting company, and Dust Networks, a Bay Area startup associated with CITRIS researchers, is demonstrating the potential for smart sensors and control systems to increase the energy efficiency of building lighting. The team is using wireless networking and communications technologies in a system capable of responding to changes, for example, in the ambient light level in a building. Light sensors fitted with wireless smart “motes” (very small networked sensor radios), respond to changes in light. As daylight levels increase, the system can automatically lower the level of electric lighting, saving energy and making the environment more pleasant and productive for the occupants. Eventually, wireless sensors will be embedded in the very structure of buildings, significantly improving system capabilities and reducing installation costs. Berkeley Lab estimates suggest that such systems have the potential to save half of the annual lighting energy used in commercial buildings. According to a CITRIS website, “A network of tiny, inexpensive sensors can make buildings vastly more energy efficient, saving as much as $55 billion in energy costs nationally and 35 million tons of carbon emissions each year. In California alone, this translates into a savings of $8 billion in energy costs and a reduction of 5 million metric tons of carbon emission annually.”

The idea of using metering and sensors to control energy use is closely tied to the concept of demand response. Demand response (DR) facilitates the quick, automatic reduction of energy use in commercial buildings, industrial facilities, and homes in response to a rising price in the cost of power or an emergency on the electric grid. The California Energy Commission is funding a new Demand Response Research Center (DRRC) that is being managed by Berkeley Lab. Almost all demand response today is carried out manually. In 2003, Berkeley Lab tested the first automatic, multi-building, demand response technology using Internet connectivity. In 2005, automated DR was incorporated for the first time into a real utility program, and research on more advanced automated DR technology is continuing.

When electricity prices rise, large commercial users can implement an automatic, preplanned program of reducing certain electrical loads of their choice. For example, they can decide in advance to dim lights or turn them off in unused areas of buildings, lower hot water temperatures, reduce air conditioning use, or shut down certain assembly lines or tools in response to an automatic signal of a power price increase or a grid emergency. In the 2003 test, as an example of a technique that might be used in the future, a fictitious electricity price similar to critical peak pricing was used to trigger the demand response event over the Internet. No one touched any control systems during the test. When a signal broadcast over the Internet indicated that the price of electricity hit 30 cents per kilowatt-hour, the buildings automatically began to lower demand by reducing lights, air conditioning, and other activities. For the test, the research team developed new technology to evaluate the capabilities of control and communications for automated demand response using energy management control systems and the Extensible Markup Language of the Internet.

Being able to respond to electricity price signals in real time can help save electricity consumers money, reduce energy consumption, and lower energy prices by making the power market more responsive to consumer needs. However, the technology to implement demand response programs in California and the rest of the U.S. is only beginning to be available, and much remains to be learned about the programs' cost-effectiveness.

In addition to CITRIS and Berkeley Lab, three associated research centers at UC Berkeley—the Center for the Built Environment, the Berkeley Wireless Research Center, and the Berkeley Sensor and Actuator Center—are also conducting demand response work related to homes. Their project harnesses the aforementioned wireless "motes," locating them throughout a house to communicate with heating and air conditioning systems, lights and other building systems. The goals of this project include: 1) creating a new thermostat that reads real-time varying price signals and automatically adjusts the house's space-conditioning equipment to best manage the tradeoffs between cost and comfort; and 2) creating a new inexpensive revenue-grade meter that allows intercommunication about energy usage with the thermostat and with the outside world.

Demand response research is also conducted by EPRI. EPRI's transmission and distribution research emphasizes developing technologies to improve the reliability, security, quality and availability of electric power. EPRI manages projects that range from developing technologies for monitoring power quality events on the electric grid to superconducting technologies for electricity transmission across the U.S.

EPRI is one of two Bay Area institutions involved in research on electricity transmission and distribution. The other is the Consortium for Electric Reliability Technology Solutions (CERTS). CERTS was formed in 1999 to research, develop, and disseminate new methods, tools, and technologies to protect the reliability of the U.S. electric power system, in part by enhancing the functioning of competitive electricity markets. CERTS members include four national laboratories including Berkeley Lab; an NSF industry-university research center; and private sector participants. The Consortium is funded by the U.S. Department of Energy and by the California Energy Commission Public Interest Energy Research Program. The program office is located at Berkeley Lab.

CERTS is developing technology solutions to protect the public interest in reliable electricity service through the transition to competitive electricity markets. The Consortium conducts research in real-time grid reliability, developing prototype software tools that will ultimately enable the electricity grid to function as a smart, switchable network. It is also conducting pioneering research to enable decentralized electricity system operations in the form of microgrids based on distributed energy resources. CERTS funds research in institutions throughout the U.S.

Examples of Bay Area-based CERTS research are two projects taking place at Berkeley Lab. One project is developing the CERTS Microgrid, a technology for allowing small local generators to operate both in parallel with and—when problems on the grid arise—in isolation from the grid. A key feature of this project is the seamless transition between the grid-connected and islanded modes of operation, which can benefit both the grid and the customer. A second project involves the Silicon Valley Leadership Group in testing the capabilities of a new low-cost power quality monitoring system called I-Grid.

With the participation of stakeholders such as businesses, manufacturers and consumers, implementing carefully written regulations and energy efficiency standards has helped businesses and residents in the State of California save billions of dollars since the 1970s. Today, the collaboration between the California Energy Commission, the California Public Utilities Commission (CPUC), the California Department of Water Resources, the private sector, and public and private research institutions has forged a mutually beneficial alliance that helps California's economy to advance, protects the environment, and reduces energy and water costs.

Beginning in the 1970s, the California Energy Commission developed state energy efficiency standards for appliances and a state building energy code, called Title 24, which have become national and international models for encouraging energy efficiency through the participation of all stakeholders. The state's appliance standards were also a model for the national appliance efficiency standards that were later passed by Congress.

This partnership continues today. Consultation with energy analysts at Berkeley Lab, for example, is providing the state with the technical expertise to develop new technologies and standards for efficient water heating, which are technologically feasible and economically reasonable in cost and payback time. The Title 24 building codes are updated every few years to incorporate the most recent marketplace technologies and practices, again with assistance from Bay Area research institutions such as Berkeley Lab and UC Davis.

Responding to opportunities in newer areas of technology development, regulators at the CPUC also draw on Berkeley Lab researchers and consulting firms in the Bay Area for scientifically validated studies to incorporate demand response, real-time pricing, and other peak power reduction strategies in state regulations. The CPUC oversees energy and natural gas efficiency programs funded through a public goods surcharge on energy bills. These programs are implemented by California's investor-owned utilities to reduce energy use in lighting, appliances, HVAC (heating ventilation and air conditioning), motors, and new construction. Many of the Bay Area research institutions named in this chapter supply the technical expertise to develop these programs on a scientifically and economically sound basis.

Recently, the CPUC awarded the University of California and the California State University system $12 million to implement energy efficiency programs on their campuses. The funding will be split equally between the two university systems. Bay Area institutions that stand to benefit from this funding include the UC campuses of Berkeley, Davis, San Francisco and Santa Cruz, and the CSU campuses of East Bay, San Francisco and San Jose. The money will fund energy efficiency retrofits, including energy-saving lighting and lighting controls; heating, ventilation and air conditioning upgrades; and improved energy management controls, as well as training for employees. Programs like these help create expertise at the implementation level, as well as a base of experience in the marketplace success of energy efficient technologies. Such programs also raise interest among students in energy science and engineering.

The Bay Area is fortunate to have a number of colleges and universities training future scientists and engineers in energy efficiency and educating citizens about the role of new energy technologies in reducing environmental impacts. The region is also home to agencies that educate the public on energy efficiency, as well as several municipalities that have taken leading roles in adopting energy efficient technologies and encouraging their residents to do the same. Finally, the region's utilities are major partners with its research institutions in field testing and developing technologies for the marketplace, as well as creating pioneering programs to encourage market penetration.

UC Berkeley's Energy and Resources Group trains graduate and doctoral students in energy and resources efficiency and other sustainable approaches to satisfying the world's energy needs. At Stanford University, students at the Precourt Institute for Energy Efficiency and the Woods Institute for the Environment can study the impacts of energy use on the environment. Both universities are also making major pushes to use resources in a more sustainable manner. UC Berkeley is implementing the recommendations of a Chancellor's Advisory Committee on Sustainability, including efforts to make campus buildings more energy efficient and to better monitor energy use. Stanford is taking similar steps to green its campus, and its Civil and Environmental Engineering Department is leading a project to build a Green Dorm which will incorporate state-of-the-art energy-efficient and sustainable building technologies and materials. In addition to being a residence, the Green Dorm will serve as a living laboratory to study efficient building systems technologies and as a public education and demonstration space. UC Davis has designated energy research and education as top campus priorities, and 32 faculty members from 11 departments are associates of the new Energy Efficiency Center, thus demonstrating the interdisciplinary cooperation that will be crucial to the development of energy-efficient technologies and products. Twelve new faculty positions have been allocated to the energy field, the largest research growth initiative on the UC Davis campus.

Flex Your Power (FYP), based in San Francisco, is California's statewide energy efficiency marketing and outreach campaign. Initiated in 2001, FYP is a partnership of California's utilities, residents, businesses, institutions, government agencies and nonprofit organizations working to save energy. The campaign includes retail promotions, a comprehensive website, an electronic newsletter, educational materials and advertising. FYP has received national and international recognition, including an ENERGY STAR Award for Excellence. The campaign is funded primarily by a Public Goods Charge from the CPUC, as well as contributing municipal power companies and other partner organizations. FYP's considerable success in its first year showed that public communications and marketing are indispensable components for getting efficiency to work. In part because of FYP's efforts, during the summer of 2001, California reduced energy consumption at peak by as much as

14 percent, and one-third of the state's commercial customers and its residents cut energy use by at least 20 percent.

PG&E provided a portion of its own headquarters building in the 1970s for tests on the energy-efficient electronic ballast for fluorescent lamps developed at Berkeley Lab. For the Advanced Consumer Technology Test (ACT2) in the 1990s, PG&E also worked with Berkeley Lab, as well as scientists in the Natural Resource Defense Council's Energy Program and the Rocky Mountain Institute, to design state-of-the-art energy-efficient homes and commercial buildings. The seven project buildings were each able to save 50 percent of comparable conventional building energy use. This collaboration continues today, with ongoing collaborative research and demonstration in commercial, residential and industrial retrofit, new construction and green design programs, with a recent focus on emerging technologies.

PG&E's Energy Center has been a California leader in demonstrating energy-efficient technologies to the public as well as to professionals (e.g., by offering specialized workshops and seminars to architects and engineers, building owners, etc.). PG&E also has an Emerging Technologies Program that seeks to accelerate the introduction of innovative energy-efficient technologies, applications, and analytical tools that are not yet widely adopted in California. Emerging technologies may include a range of products including hardware, software, design tools, strategies, and services.

The Sacramento Municipal Utility District (SMUD) has been a significant research partner as well, with a long history of interest in energy efficiency that includes championing demonstrations of cool materials in the 1990s, reducing air conditioning energy use, and providing test beds for advanced lighting systems developed by the California Lighting Technology Center.

Another focus for energy efficiency R&D is aimed at improving the structure of the current energy system to minimize energy usage and its related costs as much as possible. All of the energy that we use is delivered through systems of technologies that have been designed to work together economically and reliably. The way each system is built depends on the types of technologies that are available and the demands that are placed on it. The electricity system is a good example. Our demand for electricity varies from hour to hour and from season to season. We need to build a system that can reliably deliver energy even at peak demand, but which balances the capital and operating costs of the suite of generators to arrive at an economical result. Today's electrical system relies on a wide range of technologies with different operating and economic characteristics. For example, base load generators have a very high initial cost, but a very low operating cost. We use base load plants to cover that part of the electric load that is always there—essentially the load that is present during the night. Although expensive to build, the fact that base load generators operate 24 hours a day means that their low operating costs make up for their high initial costs. On the other hand, peaking plants have a very low initial cost, but a high operating cost. However, peaking generators must be included in the power system to cover periods of peak demands. Since peaking generators have a very low initial cost, they can inexpensively provide the capacity needed to make the system reliable. Although their operating cost is high, they are only operated during a relatively short period of time each year. In between these two extremes are the intermediate plants, which are used to cover the electric generation between the base load and the peak demands.

The key feature of these technologies is that they are dispatchable, meaning they can be turned on and off when needed to meet demands. They also tend to be physically large so they are located some distance from the point of use, requiring transmission and distribution systems to bring power to consumers. Designing systems to meet demands with these three types of generators has been common practice for many decades. However, we are now moving into a new era when new technologies with different characteristics are being developed. These new technologies include: 1) renewable generators, such as geothermal and waste-to-energy, that behave pretty much like existing generators, except that they need to be located in places where there is fuel or heat; 2) intermittent renewable technologies such as wind, photovoltaic (PV), and wave energy generators that produce power when energy is available, not necessarily when it is needed; and 3) combined heat and power (CHP) technologies that use the waste heat from electrical generation for space heating and cooling. This last technology is already being extensively used in Europe. It requires that generators be located close to the point where the heat can be used, and that generator operation take into account the value of the heat along with the value of the electricity.

Distributed energy resources (DER) technologies place smaller generators very close to the point of demand, possibly in the basement of an individual building. This saves investment in transmission and distribution and allows for the easier capture of the waste heat for CHP. Energy storage can be brought into play to allow shifts of power generation between hours of high and low demand, with expensive-to-operate peaking generators supplying the last increment of power when demand is very high, while much less expensive base load generators supply the power when demand is low. Systems with a large amount of intermittent factors could also benefit from storage technologies that allow energy to be stored when it is cheap and released when it is expensive. Demand response includes technologies that allow electricity use to be managed moment to moment, so that more energy is demanded when energy is available and cheap, and less is demanded when less energy is available. These types of technologies could make the development of systems with large intermittent generators much easier to design and more reliable.

While improving the efficiency of energy systems will lead to significant savings in energy costs in the long run, one way to capture these savings in the near future is to develop technologies that will enable consumers and businesses to use less energy in their daily lives and business operations. With this mission in mind, UC Davis received a $1 million grant from the California Clean Energy Fund (CalCEF) in April 2006 to establish the nation's first center of excellence in energy efficiency. The new center is dedicated to speeding the transfer of new energy-saving products and services into the homes and lives of Californians and consumers throughout the rest of the country.

The UC Davis Energy Efficiency Center is expected to bring together leaders in academia, industry, and the investment community to advance innovation in energy efficiency—a mission of critical importance to California. Over the next five years, PG&E will also provide $500,000 in support for the Center to meet critical startup needs (including fellowships to attract and educate outstanding students) and for a major conference that will convene worldwide energy efficiency experts. The Center also will reinforce the Bay Area's and California's standings as national and international leaders in energy efficient practices that benefit both the environment and the California economy. CalCEF awarded the grant to UC Davis because of what CalCEF officials said is the campus's exceptional commitment to developing and bringing energy efficient technology to the marketplace.

"The UC Davis Center for Energy Efficiency is going to be a laboratory for ideas of the future," said Arnold Schwarzenegger, Governor of California, "and I know that all of us working together—meaning government, people, the businesses and, of course, the brilliant minds of this center—will bring a clean, prosperous future to California."

Improving the technologies that are direct consumers of energy is another significant factor in increasing the overall efficiency of energy usage. For example, California Energy Commission data indicates that 20 percent of all electrical energy use in California is attributed to lighting. Advanced lighting technologies that show great promise for energy savings have been developed over the last 20 years and a few have had widespread implementation. However, many more opportunities exist to increase both efficiency and market penetration of these products. Additionally, educational opportunities that focus on the science of lighting design and its applications are currently quite scarce. Education programs about lighting technologies and efficient lighting applications are seriously underrepresented in college and university engineering and design departments, and most design professionals are at a loss to develop effective building lighting systems that provide both energy efficiency and aesthetically satisfying designs. It is the mission of the UC Davis California Lighting Technology Center (CLTC) to correct this deficiency by fostering the application of energy efficient lighting through technology development and demonstrations. The CLTC also operates an outreach and educational program in partnership with the lighting industry and electric utility and consumer groups. CLTC partners include the National Electrical Manufacturing Association (NEMA), the Natural Resources Defense Council (NRDC) and the DOE.

One example of the lighting efficiency projects being investigated at CLTC is an effort to devise simplified day lighting controls. The goal is to develop and demonstrate a simple fluorescent lighting on/off control based on a customizable threshold level of available light. The proposed system will be inexpensive (no dimming ballasts), commission-free (ready-to-assemble out of the box), and suitable for many retrofit applications as well as new construction. In addition, the task-ambient lighting project seeks to characterize, develop, and apply advanced task-ambient strategies and technologies to provide higher levels of occupant comfort while using about 0.4 watts per square foot of ambient lighting.

Another focus of the CLTC is the demand response lighting controls project, which is developing a cost-effective demand response technology that can be quickly and easily deployed in new and existing buildings in California. The new technology will target bi-level switching capabilities available in all commercial buildings since 1983, providing immediate load reduction upon receipt of a control signal. Another promising lighting technology is a low-energy, mercury-free field-emission lamp, which creates light through the combination of 70-year-old vacuum tube technology with the latest advances in carbon nanomaterials. The resulting lamp is inexpensive and long lasting, and it uses less energy to match the exact spectrum of natural daylight.

Berkeley Lab maintains an internationally recognized lighting research program, which has led to products such as compact fluorescent-based torchieres and solid-state ballasts. The Lighting Research Group currently maintains two open source software tools for improving lighting efficiency. Radiance is a suite of programs for the analysis and visualization of lighting in design. SUPERLITE 2.0 is a lighting analysis program designed to accurately predict interior illuminance in complex building spaces due to daylight and electric lighting systems. Both software packages are available for use free of charge.

Along with lighting, heating and cooling are other substantial areas of building energy use that are rich with opportunities for improved energy efficiency. In addition to reducing dependence on nonrenewable power, a concomitant benefit of more energy-efficient buildings is the reduction of pollution and other harmful environmental impacts. From an economic standpoint, reducing energy consumption in buildings makes further sense given that the energy costs associated with illuminating, heating, and cooling living and working spaces are a large part of overall building operational expenses. There is also evidence that sustainable design and energy efficiency in buildings provides increased occupant satisfaction and comfort, as well as positive health effects.

The integration of sustainable design in our buildings, however, does not come easily. There are some major challenges facing designers today in implementing sustainable design strategies. According to designers with Ratcliff Architects in Emeryville, California, these challenges fall into three main categories: economic myopia, lack of awareness, and the pace of technological advancements in the marketplace. Economic myopia arises as a result of architects, clients, facilities managers, and other stakeholders being focused on the up-front or first costs of construction. Often the perception of higher initial costs constrains the implementation of sustainable design strategies. Budgets rarely take into account the operating costs of buildings or any other long-term cost impacts such as utilities, worker productivity, and absenteeism which can be affected by poorly designed (unhealthy) spaces. Lack of awareness comes from the difficulty of keeping abreast of the ever-increasing multitude of sustainable design resources. Finally, technological advances are not always in step with the marketplace. While there have been great strides in energy efficiency in equipment, appliances and materials, more advanced energy-reduction technologies are not readily available, and some techniques still have development and feasibility issues that make them not yet ready for the marketplace.

Innovative building design companies such as Ratcliff Architects recognize and integrate attributes of nature with a building's design in order to decrease, and in some cases eliminate, the need for conventional fossil fuel energy. Some of the most successful energy-use-reduction strategies in buildings do not require purchased energy or mechanical assistance, since they are implemented at the very onset of design. Building orientation, for instance, involves the careful placement of a building and its components in relationship to the natural elements to better take advantage of naturally occurring phenomena including south-facing openings for winter heating and northern skies for ambient lighting.

A number of emerging technologies are now ready to be utilized by building designers, including electrochromic windows, LED lighting and Building Integrated Photovoltaics (BIPVs). In window construction, the key to energy reduction is controlling the conductance and transmittance of heat across the thickness of the assembly, including the joints where the window frame meets the wall. To control heat conductance through the glass, designers use double and even triple-paned windows. Sometimes a gas, usually argon, fills the voids between the panes, helping to further reduce energy transfer. Berkeley Lab is home to a long-standing building technologies program. Among the numerous studies being conducted are investigations into the area of chromogenics. The research centers on materials, such as glass, that can experience a variable and reversible change in optical effects after being injected with certain ions (electrically charged atoms). Chromogenic systems generally consist of two electrodes separated by an ion conductor. When applied to glass, this technology can be used to intelligently filter certain spectra of light, thereby reducing the loss of energy through the window. The Berkley Lab program also studies highly insulating and/or switchable window glazings, gas-filled panels, and integrated window/wall systems, and has created a suite of software aimed at providing guidelines and tools for building designers so that energy-saving systems are specified and used in an optimal manner.

In the area of indoor illumination, in addition to the technologies already discussed, there have also been significant advances in light-emitting diode (LED) and organic light-emitting diode (OLED) lighting. These lights do not use filaments, but instead use a semi-conductor material (organic material in an OLED) that simply illuminates by electron movements. Since there are no moving parts, LEDs are more durable. They also use energy more efficiently—easily 50 percent more efficiently than typical fixtures. Current research by companies such as San Jose's Lumileds Lighting is showing that by 2025, LED lighting will be more economical, longer lasting, and energy efficient than any incandescent, fluorescent or metal halide fixture on today's market.

UC Berkeley hosts the University of California Energy Institute (UCEI), which is a multi-campus research effort. Since its inception in 1980, UCEI's mission has been to foster research and educate students and policy makers on energy issues that are crucial to the future of

California, the nation, and the world. One of the more promising avenues of research regarding energy efficiency and consumer usage of electricity is to analyze the effects of time-varying on electricity markets. By applying a model of real-time pricing (RTP) adoption in competitive electricity markets, UCEI research simulations show that RTP adoption improves efficiency, reduces the variance and average of wholesale prices, and reduces all retail rates. However, the research indicates, too, that much of the efficiency gains of real-time price variation could be attained by varying flat rates monthly instead of annually. Monthly flat rate adjustment would have many of the same effects as RTP adoption and would also greatly simplify the logistical arrangements and added costs of an actual RTP system.

In discussions about the energy crisis and energy efficiencies, an important and often overlooked factor is the nexus between energy and water. Both are constrained resources subject to high and growing demand, and both are inexorably linked. Understanding this linkage is vital to the effective future management of both resources. For example, because water supply and management involves vast amounts of energy, the availability of freshwater resources may be curtailed by energy that is insufficient or too costly. Conversely, because the energy sector uses considerable amounts of water, insufficient water resources can reduce the supply of energy or drive up costs.

According to the California Energy Commission, preliminary estimates of California's total water-related energy consumption are large—roughly 19 percent of all electricity, approximately 32 percent of all natural gas, and some 2.7 percent of diesel fuel. Water sector use of energy will likely substantially outpace growth in other high energy use sectors. There will be greater demand for water reuse and recycling as well as energy-intensive treatment of impaired or saline water sources, a greater need to tap deep groundwater sources, and higher requirements for water storage and transport. The water sector's demand for energy will also grow due to a deteriorating infrastructure for treatment and conveyance of freshwater supplies, an increased need to treat for harmful natural constituents (such as arsenic and other contaminants introduced into the environment), and concerns over soil salinization and depletion of groundwater. Significant improvements in energy efficiency require investments in research, development, demonstration and deployment of water treatment technologies for treating an ever-growing number of contaminants.

There are water-related issues associated with supply and management in the energy sector as well. U.S. Geological Survey data shows that electricity production from fossil and nuclear energy requires 190,000 million gallons of water per day, or 39 percent of all freshwater withdrawals nationally. While only a portion of these withdrawals is consumed, the returned water is thermally and chemically affected by its use. Moreover, enough water must be available to sustain energy production and meet other needs. Much of the nation's energy fuel production is also dependent on adequate water supplies. Energy resource recovery and processing create large volumes of wastewater that require treatment for reuse or disposal. Future shifts to energy sources such as coal liquefaction or gasification, biomass, and hydrogen will place additional demands on water resources. There is increasing interest in developing new sources of water for power production, including treatment of wastewater or water produced along with energy fuels.

The Bay Area's four largest water supply agencies, the East Bay Municipal Utility District, the San Francisco Public Utilities Commission, the Contra Costa Water District, and the Santa Clara Valley Water District, recently have been exploring the development of regional desalination facilities that would benefit over 5.4 million Bay Area residents and businesses. The project would consist of one or more desalination facilities, with an ultimate total capacity of up to 120 million gallons per day. The technologies needed to improve the energy efficiency of desalination processes include membranes with increased throughput and specificity, improvements to hydrodynamic designs and other parts of the system, and alternatives to the reverse osmosis technology that is now dominant in this field. Many BASIC members and other Bay Area institutes are involved in this R&D effort.

For example, LLNL researchers have been working on alternative desalinization technologies for over twenty years. In the 1990s, LLNL licensed an innovative approach to capacitance deionization using aerogels for desalting water. In 1995, this technology was selected as one of the top 100 technology innovations of the year by the R&D 100 Awards program. Next-generation approaches and spin-offs from this original technology are currently under development, including a concept involving electrostatic ion pumping. Because electrodialysis processes have fundamental efficiency advantages over reverse osmosis, LLNL is integrating molecular modeling, membrane science and engineering expertise to push the ion selectivity and transport thresholds for electrodialysis closer to theoretical limits, improving energy efficiency potentially by an order of magnitude over current electrodialysis processes. These technologies would greatly improve operating costs and recovery for desalination across the spectrum from inland brackish waters to seawater.

In addition to being a major source of energy consumption, water systems also have the potential to store large amounts of energy. California has a number of pumped storage facilities where water is pumped to a higher reservoir during off-peak times and used to generate electricity when needed. This is currently considered to be the only commercially viable method for large-scale "storage" of electricity. One possibility for developing new pumped-storage projects is to connect two existing reservoirs or lakes with new pipelines for pumping and generating operations. A recent study from LLNL identified dozens of such reservoir pairs in California that could yield as much as 1,800 megawatts of new pumped storage. This option avoids construction of new reservoirs, but still faces challenges involved with bringing large pipelines through difficult terrain on protected lands.

LLNL and Berkeley Lab both participate in the DOE's multi-lab Energy-Water Nexus Team, which is designed to assess national needs in the energy-water arena and to identify science and technology solutions. Berkeley Lab's group is responsible for addressing the economic issues that will inevitably accompany the assessed needs and solutions. Berkeley

Lab researchers are also working with researchers at the University of New Mexico's Utton Center to identify economic and legal barriers to successful application of potential technological solutions. Other Bay Area research institutions are also looking to identify new ways of reducing energy consumption by water systems even as water demands continue to increase. At the same time, new ways will be explored for utilizing water systems as a means of storing large quantities of energy in order to meet ever-greater demands.

Finally, no serious discussion about finding ways to improve the efficiencies of existing energy technologies would be complete without mention of the workhorse technology of the industrial era, the internal combustion engine (ICE). As stated earlier in this report, transportation accounts for approximately one-third of the energy consumed in this nation and nearly two-thirds of all global energy consumption. Almost all of this is expended on some form of petroleum-fueled ICE, and yet only about 15 percent of the energy from the fuel burned in the typical ICE is actually put to use in moving a vehicle. The rest of the energy is lost to engine and driveline inefficiencies and idling. Consequently, the potential to improve fuel efficiency with advanced combustion technologies is enormous.

While a number of Bay Area research institutes are pursuing some aspect of combustion research, including computer modeling at UC Berkeley, LLNL and Berkeley Lab, perhaps the most comprehensive program is under way at SNL's internationally recognized Combustion Research Facility (CRF). Designated as a DOE national user facility—meaning that its resources are available to qualified researchers across the nation—SNL's CRF is home to about 100 scientists, engineers, and technologists, who conduct basic and applied research aimed at improving our nation's ability to use and control combustion processes. CRF research ranges from studying chemical reactions in a flame to developing an instrument for the remote detection of gas leaks. Most of the CRF's work is done in collaboration with scientists and engineers from industry and universities.

The race to find solutions to the energy crisis is a marathon not a sprint. Commercially viable alternative energy technologies that are both renewable and carbon-neutral are not just around the bend, but are far down the road, and despite the best research efforts, success will not be achieved overnight. In the interim, increasing the efficiencies of our current energy technologies can help buy us the time we need.

Conclusion

Even if vast new and easily recoverable petroleum deposits were to be discovered in the Arctic National Wildlife Refuge or elsewhere in the world, the need to develop alternative energy sources would still be imperative. The reason is global warming. In the strongest of terms, the world's most authoritative scientists and scientific agencies, including the Intergovernmental Panel on Climate Change (IPCC) of the United Nations and the American Association for Advancement of Science (AAAS), have concluded that the burning of fossil fuels is having a profound and adverse affect upon global temperatures.

According to the IPCC's latest report, global temperatures are expected to climb anywhere from 3.2 to 7.8 degrees by the end of this century, compared to an increase of 1.2 degrees in the 20th century. This trend, like a runaway train, may already be too late to reverse even if greenhouse gas emissions were to be stabilized. Additionally, as has been previously stated in this BASIC report, the rate of greenhouse gas emissions is expected to escalate with the increasing industrialization of nations such as China and India.

In the science fiction film trilogy, The Matrix, the filmmakers described a future in which the earth's atmosphere has been blackened by humans to the point where sunlight can no longer penetrate. With the intensive use of fossil fuels, the idea of humans damaging their own atmosphere isn't fiction. It has taken the human race less than 200 years to consume a substantial portion of the fossil fuels built up over hundreds of millions of years, and there will be no replenishment. What this adds up to is a lose-lose situation, but one that can be corrected.

Matrix-like doomsday scenarios need not be our destiny. Energy experts agree that it is within our scientific capabilities to develop a large and diverse portfolio of clean and renewable energy technologies. In the near term, major gains can be made through increased energy efficiency and a focus on the cleaner burning of existing carbon resources. In the longer term, fuels extracted from biomass, energy generated via electrochemical or magnetic technologies, and power derived from geothermal, hydrogen, solar, wind or nuclear processes can all play a role in weaning society away from its fossil fuel addiction. The member institutes and companies in BASIC, in conjunction with other organizations in the San Francisco Bay Area, are working to provide the broad-based energy portfolio that these times demand.

Success will come, but the shift from petroleum and other fossil fuel energy sources will not take place overnight. To have a significant commercial and environmental impact, alternative energy technologies will have to be adopted on a wide scale. In some cases, this will require the establishment of new infrastructures, a process that could take decades to complete. In the meantime, conserving the resources we now have by improving the efficiencies of the energy technologies we use today will be paramount. Again, the member organizations of BASIC are at the forefront. From advanced techniques for heating, cooling and lighting our buildings and devices, to new methods of monitoring and controlling our energy usage, researchers in BASIC member organizations are finding new ways to conserve energy resources, preserve the environment and spare the air.

Through partnerships forged among the wealth of national laboratories, universities, high-tech R&D firms and startup companies that comprise its member institutes, and through the fostering of multidisciplinary collaborations between the scientists and engineers who staff those institutes, BASIC has assumed a leadership role in the effort to develop alternatives to fossil fuel energy technologies. These efforts promise to fuel our future while preserving our atmosphere. That is a promise with which we can all live and prosper.

Contributing Organizations

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California Energy Commission
California Public Utilities Commission
Chevron Corporation
Consortium for Electric Reliability Technology Solutions
Dust Networks
EPRI
Farasis Energy
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GeoMechanics International
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