An Overview of Energy Conservation Research Opportunities

Executive Summary

W. J. Hopp	W. C. Cliff
S. G. Hauser	R. E. Williford
G. J. Hane	T. A. Williams
W. E. Gurwell	W. B. Ashton
S. P. Bird	

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RESEARCH OPPORTUNITIES

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Richland, Washington 99352

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PREFACE

This document is a study of research opportunities that are important to developing advanced technologies for efficient energy use. The study's purpose is to describe a wide array of attractive technical areas from which specific research and development programs could be implemented. Research areas are presented for potential application in each of the major energy end-use sectors. The analysis is unique in that it employs a systematic process for both identifying and screening candidate energy conservation research areas. The study team was comprehensive in its review of aggregate energy consumption and employed explicit criteria to evaluate the technology research areas.

This study was completed for the Division of Energy Conversion and Utilization Technologies (ECUT) in the Department of Energy. The division's mission is to identify and research long-range technology concepts that are attractive for more efficient energy use. To meet its goals, the ECUT staff has established a planning and systems analysis project that was responsible for conducting this study.

This report is one of a series of studies in support of the ECUT research planning effort. Other documents in the series contain assessments of energy conservation technology areas, methods to appraise research projects for support, and data reference sources. Publications from this project include:

Hopp, W. et. al. 1981. Identification of Energy Conservation Research Opportunities: A Review and Synthesis of the Literature. PNL-3966, Pacific Northwest Laboratory, Richland, Washington.

Hopp, W. et. al. 1981. An Overview of Energy Conservation Research Opportunities. PNL-3944, Pacific Northwest Laboratory, Richland, Washington.

U.S. Department of Energy. 1981. The 1981 Work Element Appraisal. DOE/CE-0024, U.S. Department of Energy, Washington, D.C.

T. L. Willke
Project Manager

AN OVERVIEW OF ENERGY CONSERVATION RESEARCH OPPORTUNITIES

EXECUTIVE SUMMARY

In 1981 the Pacific Northwest Laboratory (PNL) conducted a study to systematically review the buildings, transportation, and industry energy end-use sectors and to identify and screen research and development (R&D) opportunities that show potential to improve the efficiency of energy conversion and use. The results of this study are intended to provide an information base describing attractive energy research opportunities. This information base provides a framework that could be used to formulate a wide variety of energy conservation research agendas.

In the process of identifying and evaluating energy conservation research options, a companion report was produced and titled Identification of Energy Conservation Research Opportunities: A Review and Synthesis of the Literature, PNL-3944. In this report the results of a preliminary review of a representative sample of the literature are described and the research opportunities suggested in these studies are categorized.

STUDY METHODOLOGY

The procedure used to identify and screen R&D opportunities was based on the premise that the technical potential for energy conservation first must be assessed before candidate areas for federal research support can be identified. After this technical potential is evaluated, research areas with the largest promise for energy conservation can be explored. To further determine the relative merits of the technologies and research options, a cost-effectiveness analysis must be performed to identify those options that are economically attractive to pursue.

Figure 1 summarizes the process followed in this study to identify, screen, and describe R&D opportunities. The process first examined energy use in the three end-use sectors. To determine areas in which large energy savings are possible, very inefficient energy uses or energy uses involving large

amounts of energy were identified. Then, to provide an interface between energy use and R&D areas, a general list of advanced energy conservation technologies addressing these energy uses was identified. Next, to focus the analysis on promising areas, the general list was screened to select the technologies that 1) offer significant energy savings and 2) require applied R&D for energy savings to be realized. For the selected, or focus, technologies the technical and nontechnical barriers to technology development were identified and example research opportunities were suggested. Also, potential energy savings were estimated, and relevant existing research programs were identified.

The process in Figure 1 resulted in a large list of general energy conservation technologies. This list was reduced to 30 technologies that were judged to meet the screening criteria, based on the presently available information. These 30 technologies are considered the most promising areas for identifying energy conservation opportunities.

A second group of technologies did not meet the screening criteria after preliminary analysis. Rejection of these technologies as candidates for federal energy conservation R&D support is explained in the main report. For example, high-efficiency electric motors offer significant energy savings but were judged to be a mature technology. Federally sponsored applied research is not needed for this technology to achieve its energy conservation potential.

Due to a lack of information, a large third group of technologies could not be shown either to meet the screening criteria or to be eliminated as candidate opportunities. For example, the Bourke engine for automobile use offers technical potential to save energy and certainly would require R&D to become commercialized. However, very little information was available on the engine's practicality, specific research requirements, and other characteristics. It was therefore left in the category of uncertain technologies for the purposes of this study. Exclusion of uncertain technologies from this analysis does not imply that they are not productive research areas. Additional analysis would be necessary to show that some of the excluded technologies offer potential research opportunities. This study focused primarily on the 30 selected technologies for which useful information was available.

RESULTS OF R&D OPPORTUNITIES IDENTIFICATION

Table 1 summarizes the information developed for the 30 focus energy conservation technologies and identifies the primary sector and energy end use to which each technology would most likely apply. Estimates of the maximum future range of energy savings from R&D are also given. These estimates were made by assuming full market penetration by the technology for the specified end-use application by the year 2010. Because some of the technologies address the same end use, these energy savings cannot be treated as additive. Additional assumptions used in estimating energy conservation potential are detailed in the body of the main report.

Table 1 also gives example research opportunities and example technical barriers for each energy conservation technology and a rating of the degree to which the estimated energy savings depend on R&D. These research opportunities and technical barriers are strictly examples, however. Definition of specific research activities and their associated technical barriers that need to be addressed to achieve the technologies must include input from the technical research communities. The R&D dependency rating is given in terms of "High," "Medium," and "Low." "High" indicates that virtually all of the estimated energy savings are judged to be dependent on technological research. "Medium" means that at least 50% of the savings depend on R&D, and "Low" indicates that less than half of the energy savings hinge on R&D.

Table 1 also identifies potential applications of the suggested R&D to other end-use sectors. These additional applications were not considered when the energy savings from the technologies were calculated. However, because these multi-sector applications could be very important in determining the cost-effectiveness of research on the technologies, quantitative consideration of these applications should be made in future studies.

The summaries of the existing research programs and nontechnical barriers relating to each technology shown in Table 1 are not exhaustive. They are presented to indicate the degree to which other organizations or nontechnical factors may affect a federal R&D role in the technology's development. The public and private research organizations that are listed as currently performing research on each technology are useful information sources to ensure that additional federal R&D is compatible with existing research programs. Nontechnical

TABLE 1. Key Information About Selected Energy Conservation Technologies

Energy End-Use Sector: Buildings								
Present Service or Device	Energy Conservation Technology	Estimated Maximum Energy Savings Quad/Year in 2010	Example Research Opportunities	Example Technical Barriers	Dependency of Energy Savings on R&D	Applications of R&D to Other End-Use Sectors	Representative Existing Research Programs	Nontechnical Barriers to Technology
Space Conditioning	Advanced Furnace/Heat Pump Systems	1-2	<ul style="list-style-type: none"> - component development - refrigerant development - gas-fired heat pumps - novel heat pumps (Ericsson, Stirling,...) 	<ul style="list-style-type: none"> - more efficient compressors, low cost, low T heat exchangers - evaporative coolers - two fluid combinations, nonozone reactive fluids uniquely suited to temperature range - higher operating efficiency - proof of concept, less complex systems 	High	Industry--some heat pump developments may be useful in waste heat recovery, although different temperature ranges require different equipment	Electric Power Research Institute Gas Research Institute	- high first cost to consumer
Space Heating	Alternate Fuels Combustion	Fuel switching could replace all fuel used for space heating	<ul style="list-style-type: none"> - health and environmental effects - corrosion control 	<ul style="list-style-type: none"> - lower particulate emissions, control indoor air quality - minimize creosote build-up, prevent acid precipitation 	Low	Industry--alternate fuels combustion for process heat and steam	Very little private research	<ul style="list-style-type: none"> - resource availability variations (biomass) - collection hazards (woodcutting)
Space Conditioning	Advanced Thermal Storage Materials	0.2-0.4	<ul style="list-style-type: none"> - improved thermal capacity - latent heat materials - thermal diodes 	<ul style="list-style-type: none"> - new materials with higher heat capacity and conductivity - phase separation, supercooling - heat transfer mechanisms, material requirements 	Low	Industry--thermal storage for load leveling	International Energy Agency Commission of European Industries Some private research	<ul style="list-style-type: none"> - aesthetic concerns over building design - building practices - building codes
Lighting	Advanced Lighting Concepts	0.1-0.3	<ul style="list-style-type: none"> - solid-state ballasts - advanced lamps (high-frequency fluorescent and electrodeless, reflective coatings) - controls (task and day-lighting) - human factors 	<ul style="list-style-type: none"> - reliability, radio-frequency interference - proof of concept - problems with user interface - problems with user interface 	Medium		Illuminating Engineers Society Lawrence Berkeley Lab--U.S. DOE	<ul style="list-style-type: none"> - aesthetic concerns over quality of light - health impacts of some lamps
Appliances	Integrated Appliances	0.5-1.5	<ul style="list-style-type: none"> - low-cost heat exchangers - sensors and controls - completely automated total energy system 	<ul style="list-style-type: none"> - greater effectiveness - user interface - highly reliable controls 	Low		Arthur D. Little	<ul style="list-style-type: none"> - high first cost to consumer - building practices - building codes

TABLE 1. (contd)

Energy End-Use Sector: Transportation

Present Service or Device	Energy Conservation Technology	Estimated Maximum Energy Savings Quad/Year in 2010	Example Research Opportunities	Example Technical Barriers	Dependency of Energy Savings on R&D	Applications of R&D to Other End-Use Sectors	Representative Existing Research Programs	Nontechnical Barriers to Technology
Automobiles	Direct Injection Stratified Charge Engine	1.5-4.2	- fuel injection systems - basic combustion research	- optimize spray distribution - emissions control	Medium	Industry--basic combustion research applicable to industrial burners	Ford Texaco Mitsubishi	- health impacts of particulate emissions
Automobiles	Improved Diesels	1.5-4.3	- DI fuel injection systems	- high-speed capability - emissions control (particulates) - health effects of emissions	Medium		BMW British Leyland Chrysler Cummins Daimler-Benz Fiat Peugot Ford General Motors Isuzu Nissan Toyo Kogyo Toyota Volkswagen	- performance--acceptability - smoke, odor - health impacts of particulate emissions
Trucks	Adiabatic Diesel	0.6-1.7	- ceramic components	- high operating temperature - friction reduction (high temperature lubricants) - emissions control	High	Industry--adiabatic industrial engines, topping cycles	Cummins--U.S. Army	- high cost
Automobiles and Trucks	Stirling Engine	2.7-7.7	- heater head - piston rod seals - control system - component optimization (fuel economy)	- isothermalization, hydrogen permeation - work fluid leaks - faster response - combustion control, optimize engine/power train combination combination	High	Industry--cogeneration, heat pumps	Mechanical Technology, Inc. United Stirling of Sweden American Motors Ricardo Ford General Motors NASA Lewis Shaker Research Co.	- high cost - materials availability
Automobiles and Trucks	Brayton Engine	2.2-6.4	- ceramic components - combustor - component design	- high operating temperature - emissions, combustion efficiency - aerodynamics of rotating components	High	Industry--cogeneration, heat pumps	Ford Chrysler General Motors Volvo Volkswagen Nissan Toyota Garret/Mack/KHD Carborundum Corning AiResearch Casting NGK Pure Carbon Co.	
Automobiles	Improved Otto Cycle Engine	1.25-3.6	- turbochargers - superchargers - constant-speed accessories - power train management	- variable geometry - variable geometry - mechanical development - reliable controls	Low		Garrett Corp. U. of Calif. U. of Mich SAI Ford Exxon	- inability of EPA mileage tests to assess benefits of improvements (e.g., constant speed accessory) - repair and maintenance

TABLE 1. (contd)

Energy End-Use Sector: Transportation								
Present Service or Device	Energy Conservation Technology	Estimated Maximum Energy Savings Quad/Year in 2010	Example Research Opportunities	Example Technical Barriers	Dependency of Energy Savings on R&D	Applications of R&D to Other End-Use Sectors	Representative Existing Research Programs	Nontechnical Barriers to Technology
Automobiles	Advanced Conventional Transmission	1.0-2.9	<ul style="list-style-type: none"> - conventional transmission - variable volume oil pump - torque converter lockup - wide ratio four-speed gear set 	<ul style="list-style-type: none"> - reoptimization - mechanical development - mechanical development - mechanical development 	Low		Auto Manufacturers	- reduced acceleration and smoothness of shifting (public acceptance)
Automobiles	Continuously Variable Transmission	0.75-2.15	<ul style="list-style-type: none"> - rolling contact at high normal loads 	<ul style="list-style-type: none"> - lubricants with high traction coefficients - wear resistant bearings - traction drive materials 	High	Industrial--applications of CVT to industrial machinery	Chrysler General Motors Ford Sunstrand Corp. Toyota Vadotec Corp. Garrett Corp. Universities (relevant basic research)	<ul style="list-style-type: none"> - uncertain maintenance requirements - public acceptance
Automobiles	Reduced Engine and Drivetrain Friction	0.4-1.1	<ul style="list-style-type: none"> - modeling - piston rings - improved lubricants - lubricant additives 	<ul style="list-style-type: none"> - analytic model of ring lubrication - piston ring optimization, new materials and coatings - low viscosity - boundary lubrications 	Medium	Industry--basic tribology research, lubricants, and materials are applicable to industrial engines and machinery	Automakers Universities (basic research)	- public acceptance of low viscosity lubricants
Automobiles and Trucks	Decreased Rolling Resistance	0.09-0.25	<ul style="list-style-type: none"> - improved tire modeling - advanced rubber compounds - hard tire/advanced suspension systems 	<ul style="list-style-type: none"> - accuracy - wear, traction, crack resistance - proof of concept 	Medium		U.S. Department of Transportation Some private research (empirical)	- lack of awareness about tire maintenance and air pressure
Automobiles and Trucks	Vehicle Weight Reduction	0.9-2.6	<ul style="list-style-type: none"> - optimize existing materials - new materials--HSLA steel, Al alloys, plastics, composites, magnesium 	<ul style="list-style-type: none"> - durability, reduced friction - forming, fabrication, durability, reliability 	Medium		Automakers Materials Suppliers (large private research efforts)	- retooling costs involved in materials changes
Automobiles and Trucks	Alternate Fuels Combustion	Fuel switching could replace all petroleum used in autos and trucks	<ul style="list-style-type: none"> - coal/shale synfuels - alcohols - hydrogen - exotic fuels (powdered, coal/wood, slurries) 	<ul style="list-style-type: none"> - combustion characteristics, emissions, engine compatibility - cold start, wear, emissions problems - feasibility study, permeation - combustion characteristics, emissions 	Medium	Industry--characterization of combustion and emissions aspects of fuels would be applicable to industrial combustion. Buildings--slurries and powdered fuels might be used for space heating	Southwest Research Institute Gulf Research Ricardo Exxon General Motors International Harvester, U.S. Army Billings Energy Research Suntech, Inc. Universities	<ul style="list-style-type: none"> - uncertain future cost and availability of petroleum - distribution difficulties in a multi-fuel system

TABLE 1. (contd)

Energy End-Use Sector: Industry

Present Service or Device	Energy Conservation Technology	Estimated Maximum Energy Savings Quad/Year in 2010	Example Research Opportunities	Example Technical Barriers	Dependency of Energy Savings on R&D	Applications of R&D to Other End-Use Sectors	Representative Existing Research Programs	Nontechnical Barriers to Technology
Process Heat, Steam	Improved Heat Exchangers	1.5-3.0	<ul style="list-style-type: none"> - improved heat exchangers - enhanced surfaces - high-temperatures heat exchanger - fluidized bed heat exchanger - plastic heat exchangers - direct contact heat exchangers 	<ul style="list-style-type: none"> - fouling, corrosion, fluid-induced vibration - greater heat-transfer coefficient - high-temperature materials - determining heat-transfer coefficients - materials development - fluid miscibility 	High	Buildings--waste heat recovery, district heating and cogeneration systems Transportation--some heat exchanger research could be utilized in advanced heat engines	Idaho Falls Nat. Lab, U.S. DOE Heat Transfer Research Institute Hague International Dupont EPRI Harwell General Atomic AiResearch Jet Propulsion Lab. Argonne Nat. Lab Many Others (specialized applications)	- cost
Process Heat, Steam	Industrial Heat Pumps	1-3	<ul style="list-style-type: none"> - Rankine cycle working fluids - heat exchangers - Stirling cycle - absorption cycle - Ericsson-Ericsson 	<ul style="list-style-type: none"> - high-temperature fluids - greater heat-transfer coefficient - greater cycle efficiency - high-temperature fluid pairs - greater cycle efficiency 	Medium	Buildings--some heat pump developments may be applicable to space conditioning, although industrial applications tend to be higher temperature and require different equipment	Oak Ridge Nat. Lab. Battelle-Columbus Westinghouse Institute of Gas Tech. Gas Research Institute Carrier Corp. General Electric Monsanto Thermo Electron Sunstrand Nat. Highway Safety Council	<ul style="list-style-type: none"> - unfamiliarity in many industrial applications - cost
Electricity/Process Heat & Steam	Cogeneration Technologies	2-3	<ul style="list-style-type: none"> - fluidized bed combustion - alternative fuels combustion - component compatibility - high-temperature gas turbine - high-temperature air preheaters - fuel gas cleanup systems and coal gasifiers - working fluids for bottoming cycles 	<ul style="list-style-type: none"> - higher temperature capability - emissions - erosion - high-temperature materials - reliability - tars and particulate emissions - high-temperature fluids 	Low	Buildings--total energy systems (cogeneration) for buildings	Westinghouse General Electric Thermo Electron Carrier Sunstrand MTI Garrett AiResearch	<ul style="list-style-type: none"> - capital costs - uncertainty with new role for industry
Process Control	Systems Controls and Sensors	0.8-8	<ul style="list-style-type: none"> - smarter sensors - instrument performance - flame quality sensors - fuel analysis sensors - stack gas measurement - harsh environment sensors - systems methodology and modeling 	<ul style="list-style-type: none"> - new physical sensing principles - accuracy, speed of response - accuracy - accuracy - durability in erosive environments - durable materials - optimizing complex systems 	Medium	Transportation--microprocessor control of engine, transmission and auxiliaries Buildings--control of space conditioning, lighting and integrated appliances	National Bureau of Standards Much private research into microprocessors	
Materials	Scrap Recycle	2.5-3.5	<ul style="list-style-type: none"> - processing aluminum alloy steel - titanium - copper - tires - plastics 	<ul style="list-style-type: none"> - detection, classification, separation methods - eliminate impurities - separate alloys - remelt - chemical reduction - size reduction - separation 	Medium		EPA Bureau of Mines Dept. of Agriculture American Society for Testing Materials	<ul style="list-style-type: none"> - uncertain future attitudes and actions concerning recycling (presents risk to firms marketing equipment)

TABLE 1. (contd)

Energy End-Use Sector: Industry

Present Service or Device	Energy Conservation Technology	Estimated Maximum Energy Savings Quad/Year in 2010	Example Research Opportunities	Example Technical Barriers	Dependency of Energy Savings on R&D	Applications of R&D to Other End-Use Sectors	Representative Existing Research Programs	Nontechnical Barriers to Technology
Process Heat and Steam	Industrial Insulation	0.25-0.5	<ul style="list-style-type: none"> - hot wall refractories - basic data on properties - rigid insulation for steam systems 	<ul style="list-style-type: none"> - durability under high temperature conditions long-term performance - better mechanical properties and lower thermal conductivity 	Low	Buildings--basic research may be useful in buildings insulation, although applications differ greatly	American Society for Testing Materials National Bureau of Standards	- cost
Distillation	Critical Fluid Extraction	0.6-1.0	<ul style="list-style-type: none"> - improved solvents - additional applications 	<ul style="list-style-type: none"> - improved distribution coefficient, solvent selectivity - identification 	High		Arthur D. Little, Inc. National Bureau of Standards	
Concentration of Black Liquor (Pulp Industry)	Freeze Crystallization	0.1	<ul style="list-style-type: none"> - process techniques 	<ul style="list-style-type: none"> - nontriple point freezing to minimize losses of volatile gases 	High	Industry--food concentration (acetic acid, orange juice, milk)	Concentration Specialists, Inc.	
Chemical Reactions (Chemical Industry)	Catalysts	0.18-0.95	<ul style="list-style-type: none"> - study of surface science 	<ul style="list-style-type: none"> - fundamentals of catalyst mechanisms, selectivity 	High	Industry--petroleum industry chemical reactions. Emissions control Transportation--emissions control, fuel catalysts	All major chemical and petroleum industries	- proprietary information
Water Removal	Improved Drying Technologies	0.4-0.6	<ul style="list-style-type: none"> - vapor compression - heat pump drying - centrifugal fluidized bed drying - microwave freeze drying 	<ul style="list-style-type: none"> - higher efficiency - higher efficiency - fluidization characteristics of bed materials - "microwave breakdown" (ionization) 	Medium		Agricultural Universities (U.C. Davis, Cal. Poly, San Luis Obispo, Michigan State, U. of Minn.) Dept. of Energy	- lack of information available in industry
Mechanical Drive/Industrial Engines	Alternate Fuels Combustion	Fuel switching could replace all fuels used in industrial engines	<ul style="list-style-type: none"> - emissions - materials compatibility - slurries - component compatibility 	<ul style="list-style-type: none"> - NO_x emissions control - corrosion resistant materials - atomization, injection, particle-liquid interaction optimization, radiation loss and control - slag formation from low-Btu gas in turbine 	Medium	Transportation--much research would apply to use of alternate fuels in vehicle engines	Southwest Research Institute	- slow (20 yr) turnover of industrial engines
Energy Conversion, Chemicals Production, Separation Processes	Genetic Engineering	<p>Fuel switching to biomass could replace most natural gas used in industry</p> <p>Fuel switching to biomass could replace some petroleum used in organic chemicals production</p>	<p>general assessment of:</p> <ul style="list-style-type: none"> - separation and material recovery applications - energy conversion of biomass to hydrogen, methane, or ethanol - chemical feedstock processing 	<ul style="list-style-type: none"> - identification of genetic systems and vectors - immobilization of cells 	High	Transportation--fuels produced through genetic engineering could be used in vehicle engines	Pharmaceutical Research: Bethesda Research Labs Biogen Cetus Genetech Genex Molecular Genetics New England Biolabs	<ul style="list-style-type: none"> - human health and environmental concerns - philosophical dilemma
Industrial Engines/Mechanical Drive	Tribology	1.2-1.3	<ul style="list-style-type: none"> - rolling contact - sliding (abrasive) wear - lubricants - nonlubricated materials - seals and bearings 	<ul style="list-style-type: none"> - elastohydrodynamic lubrication technology, viscous properties - wear particle generation - high-temperature capability - high-temperature, durable materials - high-temperature, durable materials 	High	Transportation--much of the fundamental work in tribology would apply to friction and wear reduction in vehicle engines. Also, adiabatic diesel and CVT would benefit from research	Pacific Northwest Laboratory NASA Lewis Jet Propulsion Lab. Universities National Center for Tribology, Risely, England	- lack of awareness of tribology technology

barriers could affect the ultimate market penetration, and thus the ultimate energy savings from the technologies. Although these issues were not quantitatively evaluated in this study, they are clearly important in making decisions concerning federal research support of individual technologies.

Before the information presented in Table 1 can be used to develop a prioritized list of recommended research for federal involvement, additional work is necessary. A detailed analysis of R&D program cost effectiveness should be performed. This analysis should consider policies that define the appropriate role of federal government research, the market potential of each technology, and the degree to which the needed research for each technology is being covered in existing research programs. Because generation of an agenda of recommended research was not a goal of this study, such an analysis was not undertaken. However, to understand the merit of this type of study, a subjective assessment of these factors is useful. The following general conclusions concerning federal roles for R&D support are based on the perceptions of the study team upon completion of this study.

Because the buildings end-use sector is not very technology intensive, the majority of the high energy conservation potential in buildings was therefore judged not to be dependent on advanced R&D. Thus, the process followed in this study points to relatively few research opportunities in buildings. One opportunity, advanced heat pumps, offers energy conservation potential even though existing heat pumps could save large amounts of energy. Even small improvements in efficiency offer significant energy savings because the space heating of buildings is such a large energy use. Advanced lighting concepts may offer promise in commercial buildings, although research into human factors and advanced controls may ultimately save more energy than advanced bulbs. Health and environmental effects of alternate fuels combustion in buildings (e.g., particulate emissions and indoor air degradation) also offer a potential federal research opportunity area. Private industry is considered unlikely to perform the necessary research in this area because the benefits would accrue in the form of improved health and environmental quality, rather than as profits to the firm.

In transportation, energy use is already quite technology intensive. Therefore, technology improvements are needed to achieve the conservation

potential of this sector. Private auto manufacturers have very substantial research capabilities with which to address the technology needs of automobiles. For example, engine and vehicle design are product development activities that would be undertaken by the private sector. On the other hand, federally supported research should be restricted to activities that build up a general technology information base but which do not restrict the product design options of private industry. Example federal research activities that would support private automotive research include development of ceramic components for heat engines, fundamental studies of tribology, combustion research, modeling of tires, development of lightweight materials, and characterization of alternative vehicle fuels.

In industry the federal government could support energy conservation research in two ways. First, it could support research on generic industrial energy conservation technologies and improved generic industrial unit processes, which are cost effective when applied to industry as a whole but which do not offer sufficient benefits to any single industry to justify private development. Second, the government could support long-range research into advanced basic materials processes that are too high risk for private industry. Development of advanced basic materials processes would not only save energy but would also improve the economic viability of domestic basic materials industries on the world market.

Generic industrial energy conservation technologies and unit processes in which federally supported development appears important include advanced heat exchangers, advanced industrial heat pumps, sensors and control methodologies, methods of scrap materials separation, industrial insulation, and improved distillation and water removal processes. Attractive research support of generic industrial technologies includes characterization of alternate industrial fuels, research into the basic mechanisms of catalysts and chemical processes, investigation of the energy conservation application of genetic engineering, and fundamental studies of tribology.

Although this study did not intend to provide a list of innovative basic materials processes, several were uncovered during the analysis of industrial energy conservation opportunities. This list includes ore-to-powder systems,

direct one-step steelmaking and powder metallurgy in the steel industry, thermal reduction of bauxite to Al-Si alloy in the aluminum industry, submerged combustion in glassmaking furnaces, and advanced food sterilization processes in the food processing industry. Additional work is needed to identify and evaluate a more comprehensive list of options for such long-range research into advanced basic materials processes.

Table 2 summarizes the major R&D opportunities where federal involvement appears justified.

CONCLUSIONS

Through a systematic review of energy use in the end-use sectors, this study provides a consistent, application-oriented review of energy conservation technologies. Screening the technologies according to their energy conservation potential and need for research focused the analysis on several key areas of high potential promise. The main report of this study provides a large body of relevant information on the selected energy conservation technologies. However, the main report is more than a simple data book of facts and figures about promising energy conservation technologies. Through the investigation of long-term applied research opportunities directed at the more efficient use of energy, this study makes a step toward selecting the components of a federal energy conservation research agenda. Analytical activities that need to be completed in the future to continue the process initiated in this study include the following:

- develop additional information on the research potential of technologies judged uncertain in this study due to lack of data
- complete a systematic study of advanced basic materials processes that are promising from an economic and an energy conservation standpoint, but which require long-term, high-risk R&D
- quantitatively compare R&D benefits and cost by performing a formal cost-effectiveness analysis, which includes consideration of the proper mix of public and private research, multi-sector applications,

TABLE 2. Promising Energy Conservation Research Opportunities

Buildings

- development of advanced heat pump concepts (Stirling, Ericsson, gas-fired, working fluids)
- research into advanced lighting technologies
- control of health and environmental impacts of alternative fuels combustion

Transportation

- ceramic components for heat engines
- fundamental tribology (sliding and rolling wear, high-temp. lubrication)
- fundamental combustion research
- modeling of tires
- fundamental development of lightweight materials
- characterization of alternative vehicle fuels

Generic Industrial Technologies

- studies of heat exchanger operation and materials
- development of advanced industrial heat pumps (Stirling, Ericsson-Ericsson, absorption, working fluids)
- development of advanced sensors and control methodologies
- study of methods of scrap materials separation
- fundamental studies of industrial insulation (durability, high-temp. performance)
- development of improved distillation and water removal processes (critical fluid processes, membranes, freeze crystallization, drying processes)
- characterization of alternative industrial fuels
- studies of basic mechanisms of catalysts and chemical processes
- investigation of applications of genetic engineering to energy and chemicals conversion
- fundamental tribology (friction, wear, lubricants, materials)

Advanced Basic Materials Processes

- ore to powder steelmaking
- direct one-step steelmaking
- powder metallurgy
- thermal reduction of bauxite to Al-Si alloy
- submerged combustion glassmaking
- food sterilization processes

and the commercial market potential of each of the technologies selected in this study and other promising technologies identified through further analysis.

The analysis performed in this study, combined with these additional activities, will assist federal research in fulfilling an important role in developing vital energy conservation technologies.

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