EMERGING TECHNOLOGIES TO IMPROVE ENERGY EFFICIENCY IN THE RESIDENTIAL & COMMERCIAL SECTORS

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TABLE OF CONTENTS

Chapter	Title	Page
	Executive Summary	v
1	Project Description	1
2	Medium and High Priority Emerging Technologies	15
	Golden Carrot Refrigerator/Freezer	16
	200-300 kWh Refrigerator/Freezer	18
	Advanced Freezer	20
	Horizontal Axis Clothes Washer	22
	High Spin Speed Clothes Washer	26
	Automatic Clothes Washer Controls	30
	Bubble-Action Washing Machine	32
	Microwave Clothes Dryer	34
	Heat Pump Clothes Dryer	36
	Low Water and Energy Use Dishwashers	38
	Low-Temperature Dishwashing Detergents	42
	Low-Powered Television Sets	46
	General Service Halogen IR	48
	Coated Filament Incandescent	50
	Hafnium Carbide Crystal Filament Lamps	52
	100W Equivalent Screw-in Fluorescent	54
	Compact Fluorescent Floor and Table Lamps	56
	Dimmable Compact Flourescents	58
	Fluorescent Surface Wave Lamp	60
	DC Lighting System	62
	Scotopic Lamp	64
	Advanced Reflector Design	66
	Thermal Bridging for Fluorescent Fixtures	68
	Lower Cost Dimmable Ballasts	70
	Integrated Fixtures and Controls	72
	Architectural Daylighting Devices	74
	Electrodeless HID	76
	High R Windows	78
	High-Efficiency Packaged Air Conditioners	80
	Ground Source Heat Pump	82
	Cool Ceiling with Displacement Ventilation	84
	Cool Storage Roof	86
	GAX Absorption Heat Pump	88
	Indirect/Direct Evaporative Cooling	90
	Adsorption Heat Pump	94
	Improved Ducts and Fittings	96
	Internal Access Duct Sealants	98

	Zeotropic Refrigerants	100
	Electrohydrodynamic Heat Transfer Enhancement	102
	Pilotless Instantaneous Gas Water Heater	104
	Combined Refrigerator/Water Heater	106
	Ultrasonic Faucet Control	108
	High-R Case Doors	110
	Very Low Head Pressure	112
	Supermarket Integration	114
	Green Plug Motor Controller	116
	Switched Reluctance Drive	118
	Five-Phase Synchronous Motors	120
	Low-energy Desktop PC	124
	Improved Inkjet Printers and Faxes	128
	Improved Cold-Fusing and Low-Energy Fusing Copiers, Printers, and Faxes	130
	Ozonated Commercial Laundering	132
3	Other Emerging Technologies	135
	Appliances	135
	Lighting	136
	Building Shell	140
	Space Heating and Cooling	142
	Water Heating	146
	Commercial Cooking	149
	Drivepower	146
	Office Equipment	147
	Miscellaneous	151
4	Discussion and Conclusions	153
	References	161

Appendices

A	Existing but Underutilized Technologies	173
B	Advanced Technologies	177

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EXECUTIVE SUMMARY

INTRODUCTION

Utility DSM programs and DSM plans are largely limited to technologies that are on the market today. However, new technologies enter the market every year. As a result, by 2010, DSM options are likely to be very different from those being promoted today. A look at technologies that are likely to emerge in the next decade can aid utilities in developing long-range program plans. Furthermore, near-term utility actions can accelerate the commercialization of promising new technologies. In order to target these actions, utilities need to know which technologies are most promising. To address these needs, the California Conservation Inventory Group (CCIG -- a consortium of California utilities, government agencies, and public interest organizations) commissioned this study.

SCOPE

The objective of this study is to identify specific new technologies that can be part of future demand-side management efforts in California. Results of the study:

1. Provide information that can be used to assess California's ability to rely on DSM resources in the long-term.

2. Identify programs and policies that can be pursued in the short-term to encourage the effective development and deployment of these emerging technologies as soon as possible.

For this project, *emerging technologies* are defined as technologies that are not being widely promoted to consumers today, and which have been commercialized or are likely to be commercialized over the 1991 to 2002 period. This study does not include technologies that were commercialized before 1991 -- these are considered existing technologies, technologies which are being investigated by another CCIG project. The one exception to this rule is that when new advancements have the potential to reduce equipment costs by at least 1/3, they were included in this study (as a result of this exception, ground source heat pumps and dimmable electronic ballasts are included). Similarly, the project scope does not include technologies that are unlikely to be commercialized in the next decade, because data on these technologies are likely to be particularly imprecise, and because these technologies will probably have only a limited impact within the timespan of current utility and state plans (typically these extend to 2010).

Furthermore, to keep the project manageable, the project team and CCIG further agreed to limit the scope to measures which use electricity and natural gas in the residential and commercial sectors. Industrial and agricultural sectors measures, and measures to improve the efficiency of oil and wood use are not included, unless these measures can also save electricity and/or natural gas in the residential and commercial sectors. However, many of the commercial sector technologies are also applicable to the industrial and agricultural sectors.

APPROACH

A seven step approach was used for this project. First, lists of technologies that might fall within the project scope were compiled. Second, these technologies were evaluated and placed on either the existing technology, emerging technology, or advanced ideas list. Third, preliminary data on technology costs and savings were collected to divide the emerging technologies list into medium/high priority and low priority technologies. Fourth, more detailed research was conducted on the medium/high priority emerging technologies and the results compiled into written summaries and numerical database entries. Fifth, more limited research was conducted on the low priority emerging technologies and brief write-ups prepared. Sixth, data on medium and high priority technologies were examined and criteria were developed to distinguish high priority technologies from medium priority technologies. Finally, all of the data were compiled into this written report and companion database.

Technologies were ranked based on their cost of saved energy and energy savings potential. Cost of saved energy is the estimated levelized cost of each measure (in 1992 $), assuming a 5% real discount rate over the life of the equipment (5% is based on the real rate of return earned at present by the average utility). Costs used to calculate this value include equipment, installation, and maintenance costs but not the costs of programs that may be needed to promote each measure. Costs are based on typical purchase quantities and reflect likely prices once a technology is well established in the marketplace. For measures which are primarily appropriate for use in new construction or replacement of worn-out equipment, measure costs are the incremental cost between the high efficiency measure and the cost of a standard efficiency measure. For measures which are appropriate for retrofit situations, measure costs are the full cost of the measure.

Energy savings potential is an estimate of the amount of energy that can be saved in California in 2010 from each technology, assuming full penetration in applications for which each technology is technically feasible and likely to be cost effective from a consumer's perspective. For example, savings from daylight dimming systems are counted only for those spaces with adequate daylight. In addition, for technologies which are only likely to be cost-effective or appropriate in new construction and equipment replacement situations (when existing equipment wears out and must be replaced), potential energy savings are constrained by the commercialization date of the technology and the pace of equipment purchases for new and replacement applications.

Energy savings potential is expressed as a percentage of total projected energy use in residential and commercial buildings in California in 2010. The calculations include energy losses at the power plant and transmission lines and are relative to the approximately 3 Quads (quadrillion -- 10^{15} -- BTUs) of energy that California residential and commercial buildings are projected to use in 2010. For example, if a measure has a savings potential rating of 1%, this means that full adoption of the measure in all suitable applications will reduce projected energy use in California buildings in 2010 by 1%. There is extensive overlap between the technologies listed and hence savings potentials are generally NOT additive.

Energy savings were calculated relative to technologies which are likely to be widely used in

California in the mid-1990s. For example, appliance savings are relative to federal minimum efficiency standards that take effect in the 1990-1994 period. Energy savings are based on typical operating conditions. For example, for lighting measures, 1000 operating hours per year are assumed for the residential sector and 3500 hours per year for the commercial and industrial sectors.

Since few of the technologies covered in this report have been commercialized, estimates of measure cost, savings, and commercialization date are generally imprecise. Due to these limitations, in calculating cost of saved energy and savings potential ratings, figures were rounded to one significant digit -- finer distinctions would be meaningless. Furthermore, the data reported should be viewed as the midpoint of a range, with endpoints 10-50% higher and lower than the midpoint. The size of the range of uncertainty for each measure depends on the quality of data used. Data quality ratings for each technology are provided in the full report.

In addition, costs and savings will vary from application to application. The analyses described in this report are for "typical" applications; savings and costs are likely to be different for buildings that differ significantly from the average. This is particularly a problem when examining data on energy savings from heating and cooling measures. For climates that differ significantly from the typical California climate (approximately 2000 heating degree days and 1000-1500 cooling degree days [base 65° F]) savings will vary substantially than the values listed here.

RESULTS

The study examined 102 Technologies, including 53 medium/high priority technologies that were analyzed in depth. These technologies are listed in Table ES-1. This table also summarizes the energy savings and cost of saved energy for each technology. Taken together, these technologies have enormous potential to reduce energy use in California. When the energy that could be saved in 2010 by these technologies is summed, assuming installation in all feasible applications, the total is approximately 50% of energy use in California's buildings. This figure includes extensive double-counting of savings from similar or overlapping technologies. If only measures which do not overlap are counted, the technical potential for savings are still in excess of 25%. Even if many of these technologies never make it to market, the savings potential is still substantial. This potential indicates that opportunities for achieving considerable savings from DSM programs will continue through 2010 and beyond.

Based on the ratings for each technology, 21 high priority technologies were identified which meet two criteria -- a savings potential rating of at least 1% and a cost of saved energy of \$0.06/kWh or \$0.40/therm or less (a rough approximation of long-run avoided costs of California utilities). Of course, other factors need to be examined before decisions are made about which technologies to promote (examples of these factors are likely market acceptance and the amount of effort and time that will be required to make a technology succeed in the market). Still, prime targets for action are likely to come from this list. The 21 high priority technologies are listed in Table ES-2. Recommended next steps for advancing these technologies are also summarized in this table.

Table ES-1. Medium/High Priority Emerging Technologies.	Savings Potential Rating (% of 2010 CA R&C Energy Use)	Cost of Saved Energy $/kWh	Cost of Saved Energy $/therm
Appliances			
1. Golden Carrot refrigerator	1.6	0.03	NA
2. 200-300 kWh refrigerator/freezer	0.6	0.04	NA
3. Advanced freezer	0.3	0.06	NA
4. Horizontal axis clothes washer	1.9	-0.09	-1.9
5. High spin speed clothes washer	1.1	0.03	0.8
6. Automatic clothes washer controls	0.6	0.06	NA
7. Bubble-action washing machine	0.8	0.06	NA
8. Microwave clothes dryer	0.6	0.09	NA
9. Heat pump clothes dryer	1.3	0.05	NA
10. Low energy and water use dishwashers	0.9	0.02	0.3
11. Low-temperature dishwashing detergent	0.4	0.00	0.1
12. Low powered color TV	0.3	0.03	NA
Lighting			
1. General service halogen IR	1.2	0.01	NA
2. Coated filament incandescent	3.6	0.01	NA
3. Hafnium carbide single crystal filaments	2.6	0.02	NA
4. 100W Equivalent screw-in fluorescent	1.0	0.02	NA
5. Compact fluorescent floor & table lamps	0.5	0.03	NA
6. Dimmable compact fluorescents	0.4	0.01	NA
7. Fluorescent surface wave lamp	1.3	0.02	NA
8. DC lighting system	0.5	0.01	NA
9. Scotopic lamp	0.5	0.03	NA
10. Advanced reflector design	0.6	0.04	NA
11. Thermal bridging for fluorescent fixtures	0.5	0.01	NA
12. Lower cost dimmable ballasts	0.7	0.02	NA
13. Integrated fixtures/controls	0.3	0.04	NA
14. Architectural daylighting devices	0.3	0.04	NA
15. Electrodeless HID	0.3	-0.01	NA
Building Shell			
1. High R Glazing	0.5	NA	0.6
Space Heating and Cooling			
1. High efficiency packaged air conditioners	1.1	0.05	NA
2. Ground source heat pump	0.5	0.07	NA
3. Cool ceiling with displacement ventilation	0.3	0.12	NA
4. Cool storage roof	1.7	0.01	NA
5. GAX absorption heat pump	1.1	0.08	NA
6. Indirect/direct evaporative cooling	1.0	0.06	NA
7. Adsorption cooling	0.7	0.04	NA
8. Improved ducts and fittings	0.8	NA	0
9. Internal access duct sealants	1.2	NA	0
10. Zeotropic refrigerants	1.1	0.06	NA
11. Electrohydrodynamic heat transfer enhancement	1.8	0.06	NA
Water Heating			
1. Pilotless Instantaneous DHW	1.8	NA	0.4
2. Combination Refrigerator/Water Heater	1.2	NA	0.3
3. Ultrasonic Faucet Control	0.5	NA	0.9
Commercial Refrigeration			
1. High R case doors	0.5	0.03	NA
2. Very low head pressure	0.3	0	NA
3. Supermarket system integration	0.5	0.02	NA
Motors			
1. Green Plug motor controller	0.4	0.09	NA
2. Switched reluctance drives	1.5	0.05	NA
3. Five phase motors	1.5	0.05	NA
Office Equipment			
1a. Low-energy desktop PC (w/active matrix)	1.0	0-0.12	NA
1b. Low-energy desktop PC (without active matrix)	0.7	0	NA
2. Improved inkjet and bubblejet printers/faxes	0.7	negative	NA
3. Improved cold-fusing/low energy fusing copiers/printers/faxes	0.7	0	NA
Commercial Laundering			
1. Ozonated commercial laundering	1.9	NA	NA

Table ES-2. High Priority Emerging Technologies.

	Savings Potential Rating (% of 2010 CA R&C Energy Use)	Cost of Saved Energy $/kWh	Cost of Saved Energy $/therm	Next Steps
Appliances				
1. Golden Carrot R/F	1.6%	0.03	NA	Rebates
2. Horiz. axis clothes washer	1.9	(0.09)	(1.9)	Golden Carrot
3. High spin speed clothes washer	1.1	0.03	0.8	Golden Carrot
4. Heat pump clothes dryer	1.3	0.05	NA	Tests & demos
Lighting				
5. Gen. service halogen IR lamp	1.2	0.01	NA	R&D
6. Coated filament incandescent	3.6	0.01	NA	R&D
7. Hafnium carbide filaments	2.6	0.02	NA	R&D
8. 100 W equiv.screw-in fluor.	1.0	0.02	NA	Rebates
9. Fluor. surface wave lamp	1.3	0.02	NA	R&D
HVAC				
10. High eff. packaged A/C	1.1	0.05	NA	Golden Carrot
11. Cool storage roof	1.7	0.01	NA	Tests & demos
12. Indirect/direct evap. cooling	1.0	0.06	NA	Tests & demos
13. Internal access duct sealants	1.2	NA	0.0	Tests & demos
14. Zeotropic refrigerants	1.1	0.06	NA	R&D
15. Elec. heat transfer	1.8	0.06	NA	R&D
Water Heating				
16. Pilotless instant. DHW	1.8	NA	0.4	Rebates
17. Comb. refr./water heater	1.2	NA	0.3	R&D
Drivepower				
18. Switched reluctance drives	1.5	0.05	NA	Tests & demos
19. Five-phase motors	1.5	0.05	NA	Tests & demos
Office Equipment				
20. Low energy desktop PC	1.0	0-0.12	NA	Education
Other				
21. Ozonated laundering	1.9	NA	NA	Tests & demos

In order to realize the large savings available from emerging technologies, the actions listed in Table ES-2, and other follow-up actions will be needed. California utilities and state agencies can help spearhead these efforts. In addition, efforts to advance these technologies should be tracked and evaluated so that programs and policies to advance emerging technologies can continue to be refined. Furthermore, efforts to promote existing technologies should be reviewed, to make sure that promising existing technologies are receiving adequate attention. An appendix to the full report lists some of the existing technologies that may not be receiving adequate attention. Finally, the CCIG should plan to assess emerging technologies for the industrial and agricultural sectors, and to periodically review and revise this research on emerging technologies for the residential and commercial sectors. While some of the measures covered in the present study can be used in the industrial and agricultural sectors, many new additional technologies are being developed that can save a substantial amount of energy in the industrial and agricultural sectors. Updates to the present study will allow data to be revised based on current information, and can include new technologies that emerge over the next few years.

Chapter 1

PROJECT DESCRIPTION

INTRODUCTION

Electric and gas utilities are increasingly turning to integrated resource planning (IRP) to develop long-range plans that project energy demand each year and identify the resources that will be used to meet this demand. These plans generally include a mix of both supply-side resources (e.g. power plants and gas pipelines) and demand-side resources (e.g. energy efficiency and load management measures installed in customer facilities).

In developing estimates of the costs and savings of demand-side management (DSM) measures for the short term, utilities can look at the costs and savings of technologies now on the market. However, many of the DSM measures that will be promoted over the long term are not yet on the market. Due to this limitation, some utilities assume that DSM efforts will phase out over the long term, after existing DSM technologies saturate the marketplace. Alternatively, other utilities include "generic" DSM measures in their plans, based on costs and savings from existing measures. These estimates are typically little more than guesses, but they do provide a placeholder for new technologies.

Neither approach is an especially reliable way to project future DSM resources. The former approach is sure to underestimate the DSM resource, because savings from new technologies are sure to be greater than zero. The latter approach is a little better, but is subject to a high degree of uncertainty. To address this problem, the California Conservation Inventory Group (CCIG --a consortium of California utilities, agencies, and organizations) commissioned this study on emerging efficiency technologies.

SCOPE

The objective of this study is to identify specific new technologies that can be part of future demand-side management efforts in California, for the following reasons:

1. To provide information that can be used to assess California's ability to rely on DSM resources in the long term.

2. To identify programs and policies that can be pursued in the short term to encourage the effective development and deployment of these emerging technologies as soon as possible.

For this project, *emerging technologies* are defined as technologies that are not being widely promoted to consumers today, and which have been commercialized or are likely to be commercialized over the 1991 to 2002 period. It is these technologies that are the focus of this study.

This study does not include technologies that were commercialized before 1991 -- these are considered existing technologies, technologies which are being investigated by another CCIG project. The one exception to this rule is that when new technologies have the potential to reduce equipment costs by at least 1/3, the technology is included in this study. Similarly, the project scope does not include technologies that are unlikely to be commercialized in the next decade, because data on these technologies are likely to be particularly imprecise, and because these technologies will probably have only a limited impact within the time-span of current utility and state plans (typically these extend to 2010).

However, in an effort to ensure that neither existing nor future technologies are unforgotten, Appendix A contains lists of existing but underutilized technologies and Appendix B contains lists of advanced ideas. If a product was commercialized in 1990 or earlier, and it is not widely being promoted to consumers, then it is included in the existing but underutilitized technologies list. If a technology is not actively being worked on or if it is unlikely to be commercialized by 2002, then it is on the advanced ideas list.

To keep the project scope to a manageable level of work, the project team and CCIG further agreed to limit the scope to measures which use electricity and natural gas in the residential and commercial sectors. Industrial sector measures and measures to improve the efficiency of oil and wood use are not included, unless these measures can also save electricity and/or natural gas in the residential and commercial sectors. In particular, many of the commercial technologies are also applicable to the industrial sector.

APPROACH

A seven step approach was used for this project. First, lists of technologies that might fall within the project scope were compiled. Second, these technologies were evaluated and placed on either the existing technology, emerging technology, or advanced ideas list. Third, preliminary data on technology costs and savings were collected to divide the emerging technologies list into medium/high priority and low priority technologies. Fourth, more detailed research was conducted on the medium/high priority emerging technologies and the results compiled into written summaries and numerical database entries. Fifth, more limited research was conducted on the low priority emerging technologies and brief write-ups prepared. Sixth, data on medium and high priority technologies were examined and criteria were developed to distinguish high priority technologies from medium priority technologies. Finally, all of the data were compiled into this written report and companion database.

Many of these steps are self-explanatory. However, further descriptions of several of these steps are provided below.

Initial Technology Lists

In compiling the initial technology lists, the project team drew from a wide variety of sources including:

* Existing ACEEE, DEG and E-Source databases and unpublished reports,

particularly ACEEE research for the New York State Energy Office, DEG's work for the Pacific Gas & Electric Company ACT^2 project, and E-Source's work for pending updates to its State-of-the-Art series.

* Research sponsored by the Electric Power Research Institute, the Gas Research Institute, and the American Society of Heating, Refrigeration and Air Conditioning Engineers.

* Research efforts by California utilities and other utilities with active R&D programs.

* Research by the national laboratories, particularly Lawrence Berkeley Laboratory, Oak Ridge National Laboratory, Pacific Northwest Laboratory and the National Renewable Energy Laboratory (formerly Solar Energy Research Institute).

* Other research sponsored by the U.S. Department of Energy.

* Research by the U.S. Environmental Protection Agency on technologies to reduce carbon dioxide emissions.

* Research by state R&D centers including the California Institute for Energy Efficiency, New York State Energy Research and Development Authority, North Carolina Alternative Energy Corporation, Wisconsin Center for Demand-Side Research, Florida Solar Energy Center, and California Energy Commission Energy Technology Advancement Program.

* Papers published in the proceedings of ACEEE's biennial Summer Study on Energy-Efficiency in Buildings.

* Articles and notices in periodicals such as *Energy Design Update*; *Air Conditioning, Heating and Refrigeration News*; *ASHRAE Journal*; *Home Energy*; and *The Energy Newsbrief*.

* Discussions with major appliance and equipment manufacturers and with innovative smaller firms.

* Discussions with international energy experts in Canada, Europe, Israel, Australia, and the Far East.

This information was gathered through a literature search and through a series of letters and phone calls to program managers at the many organizations listed above. As a result of this process, over 200 technologies were identified.

Ranking of Technologies

The ranking scheme employed in this study is based on two variables -- cost of saved energy and savings potential. Each is explained below.

Cost of Saved Energy

Cost of saved energy (CSE) is the levelized average cost of a measure per kWh of electricity or therm of gas saved. It is calculated with the following formula:

$$CSE = \frac{\text{Measure cost} * \text{Capital recovery factor}}{\text{Annual energy savings}}$$

Measure costs are generally limited to equipment and installation costs, but where other costs such as maintenance are substantial, they are also included in the analysis. Measure costs do not include the cost of programs that may be used to promote specific measures. For measures which are primarily appropriate for use in new construction or replacement of worn-out equipment, measure costs are the incremental cost between the high efficiency measure and the cost of a standard efficiency measure. For measures which are appropriate for retrofit situations, measure costs are the full cost of the measure. Measure costs are the estimated cost after several years on the market; initial costs may be higher. Measure costs are at the retail level and are expressed in 1992 dollars.

The capital recovery factor can be thought of as the annual payments on a loan used to finance an efficiency measure, assuming an interest rate equal to the discount rate, and a loan term equal to the measure life.[1] In the calculations, a 5% real discount rate (*real* means excluding the effects of inflation -- the real rate is lower than the *nominal* rate charged by banks because the nominal rate includes an allowance for inflation). The 5% rate is based on the approximate real rate of return earned at present by the average utility. Measure lives are an estimate of the average amount of time measures are in use in residences and commercial establishments. Measure lives are often shorter than engineering lives as measured in a laboratory.

Energy savings were calculated relative to technologies which are likely to be widely used in California in the mid-1990s. For example, appliance savings are relative to federal minimum efficiency standards that take effect in the 1990-1994 period. Similarly, calculations for advanced fluorescent lighting technologies assume a base case of T8 lamps and electronic ballasts.

Energy savings are based on typical operating conditions. For example, for appliances, U.S. Department of Energy (DOE) and appliance industry data on average operating profiles were used. For lighting measures, 1000 operating hours per year were assumed for residential applications and 3500 operating hours per year were assumed for commercial applications. For space conditioning measures, a "typical" California climate was assumed: approximately 2000 heating degree days and 1000-1500 cooling degree days (base 65° F). For residential

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[1] Typically CRF is calculated using the loan payment formula in a computer spreadsheet program. The full formula for CRF is: $(d(1+d)^n)/((1+d)^n-1)$ where d is the discount rate and n the measure life. Thus, for a measure with a 10 year life, the CRF is 0.16, assuming a 10% discount rate. Note that since the CRF varies with measure life, no additional adjustment is needed in the CSE formula for measures with short measure lives.

applications, 1000 kWh/year was assumed for cooling (300 full load hours), 300 therms/year for space heating (500 full load hours), and 230 therms/year for water heating (60 gallons/day). For the commercial sector, 4 kWh/ft^2 was assumed for cooling and 3.5 kWh/ft^2 for ventilation.

Energy savings are expressed in terms of the fuel being saved -- electricity or natural gas. Where measures save both fuels, CSE is calculated for the primary fuel that is saved; savings of the other fuel are credited at the rate of $0.06/kWh or $0.40/therm (a rough approximation of marginal energy costs in California) by subtracting the monetary value of the savings from the numerator of the CSE equation. For example, if a measure that costs $60 and has a CRF of 0.20 saves 50 therms and 33 kWh per year, then the CSE is $0.20/therm saved ([$60 * 0.2 CRF] - [33 kWh * $0.06 / kWh] / 50 therms). Where a measure saves one fuel and uses more of another fuel, CSE is calculated in terms of the fuel being saved, and the same calculation process is followed except that the monetary value of the fuel whose use increases is added (instead of being subtracted) from the numerator of the CSE equation.

The CSE can be used to roughly estimate the cost-effectiveness of a measure. If the CSE is less than the retail price of a kWh or therm, then a measure is likely to be cost-effective from the consumer perspective. If the CSE is less than the marginal price of a kWh or therm, then the measure is likely to be cost-effective from the total resource cost perspective (for a discussion of the different cost-effectiveness perspectives, see Krause and Eto, 1988). However, this approach to estimating measure cost-effectiveness should only be used as a first-cut approximation. CSE only values energy savings, and places no value on demand (kW) savings. For some measures, the value of demand savings can be substantial. Also, when the CSE is calculated in this manner, program costs are excluded from the analysis. The cost of programs needed to promote different DSM measures can have a substantial impact on DSM measure cost-effectiveness.

Savings Potential

Savings potential ratings are based on the amount of energy that could be saved in California in 2010 from each technology, assuming full penetration in appropriate applications. The year 2010 was chosen as a date far enough into the future that new technologies could have an impact, yet near enough to be within the planning horizons of California utilities and technology researchers.

The savings potential calculations take into account a number of factors including:

(a) importance of each end-use to energy use in California buildings.

(b) reductions in energy use achievable with each technology.

(c) whether technology is a retrofit or a new construction/replacement technology (in the latter case, potential energy savings are constrained by the pace of equipment purchases for new and replacement applications).

(d) expected commercialization date for the technology (for new/replacement equipment this constrains the savings potential in 2010).

(e) the proportion of applications for which each technology is technically feasible (for example, daylight dimming systems can only be used in offices with adequate daylight).

The savings potential ratings are based on the proportion of energy (electricity and natural gas) used by California residential and commercial buildings that can be saved in 2010. The calculations include energy losses at the power plant and transmission lines and are relative to the approximately 3 Quads (quadrillion -- 10^{15} -- BTUs) of energy that California residential and commercial buildings are projected to use in 2010. For example, if a measure has a savings potential rating of 1%, this means that full adoption of the measure in all suitable applications will reduce projected energy use in California buildings in 2010 by 1%. There is extensive overlap between the technologies listed and hence savings potentials are generally NOT additive.

The projections of energy use in the year 2010 that underlie these calculations are summarized in Table 1-1. This data was largely developed by the California Energy Commission (CEC, 1990; CEC, 1991; Gough, 1992) but detailed allocations for lighting and office equipment come from Atkinson et al. (1992) and Piette et al. (1991), respectively.

High, Medium and Low Priority Technologies

The list of emerging technologies was divided into three priority categories (high, medium, and low) based on the CSE and savings potential ratings. High priority technologies have a savings potential rating of 1% or more <u>and</u> a CSE of no more than \$0.06/kWh or \$0.40/therm. Medium priority technologies have a savings potential rating of at least 0.3% <u>and</u> CSE's of no more than than \$0.12/kWh or \$1.00/therm. Low priority technologies have a savings potential rating of less than 0.3% <u>or</u> a CSE of more than \$0.12/kWh or \$1.00/therm. These categories are illustrated in Figure 1-1.

Figure 1-1 Breakdown of Technologies into High, Medium, & Low Categories.

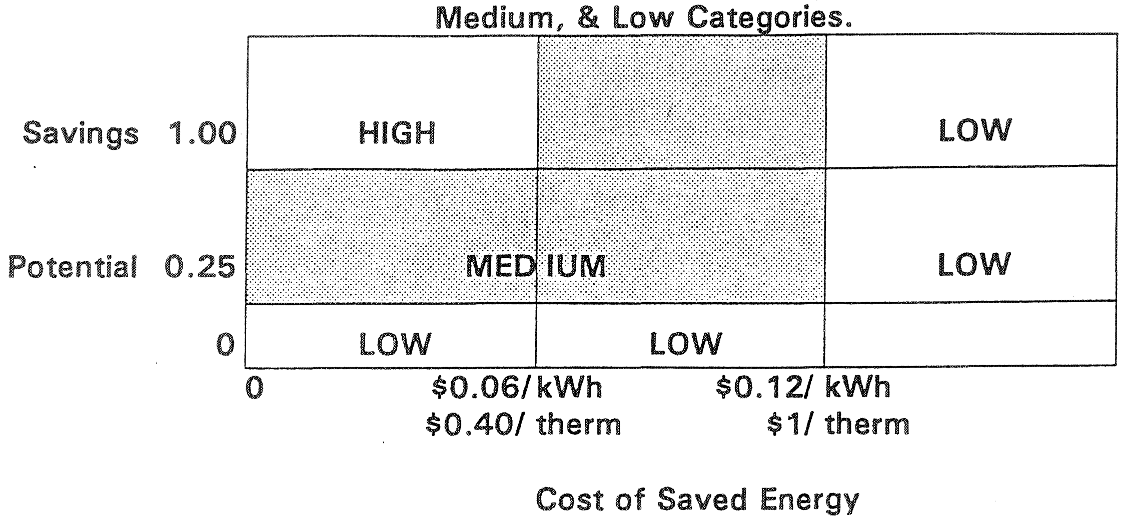

Table 1-1. 2010 Energy End-Use Breakdown for California Residential and Commercial Buildings.

RESIDENTIAL ELECTRICITY

END USE	GWH	TBTU	% TOTAL
Central A/C	5458	55.9	1.88
Room A/C	536	5.5	0.18
Evaporative A/C	538	5.5	0.18
Space Heating	3253	33.3	1.12
Furnace Fan	1453	14.9	0.50
H/W Dishwasher	886	9.1	0.30
H/W Clothwash	1373	14.1	0.47
H/W Basic	3038	31.1	1.04
Refrigerator	14464	148.1	4.97
Freezer	2867	29.4	0.99
Color TV	4550	46.6	1.56
Cooking	4268	43.7	1.47
Dishwasher Motor	2641	27.0	0.91
Clothes Dryer	6937	71.0	2.38
Clothwash Motor	876	9.0	0.30
Water Bed	2777	28.4	0.95
Lighting	12254	125.5	4.21
Miscellaneous	20875	213.7	7.17
Pool Pump	3649	37.4	1.25
Pool Water Heat	78	0.8	0.03
Tub Pump	1231	12.6	0.42
Tub Water Heat	258	2.6	0.09
SUBTOTAL	94259	965.1	32.39

RESIDENTIAL GAS

END USE	TBTU	% TOTAL
Space Cooling	6.1	0.21
Space Heat	238.2	7.99
Cooking	33.8	1.13
Clothes Dryer	19.1	0.64
H/W Clothwasher	64.8	2.17
H/W Dishwasher	45.9	1.54
H/W Basic	142.4	4.78
Miscellaneous	18.5	0.62
Pool Heat	13.3	0.45
Tub Heat	12.7	0.43
SUBTOTAL	594.8	19.96

Table 1-1. 2010 Energy End-Use Breakdown for California Residential and Commercial Buildings. (cont.)

COMMERCIAL ELECTRICITY			
END USE	GWH	TBTU	% TOTAL
Space Heating	3893	39.9	1.34
Space Cooling	17236	176.5	5.92
Fans/Pumps	11065	113.3	3.80
Water Heating	910	9.3	0.31
Cooking	546	5.6	0.19
Refrigeration	9362	95.9	3.22
Indoor Lighting	37250	381.4	12.80
Personal Computer	2820	28.9	0.97
Copier	976	10.0	0.34
Fax	705	7.2	0.24
Printer	1518	15.5	0.52
Mini/Mainframe	4013	41.1	1.38
Misc. Office Equip.	813	8.3	0.28
Outdoor Lighting	6619	67.8	2.27
Other	15647	160.2	5.38
SUBTOTAL	113375	1160.8	38.96
COMMERCIAL GAS			
END USE		TBTU	% TOTAL
Cooking		13.0	0.44
Space Cooling		10.6	0.36
Other		137.0	4.60
Refrigeration		1.0	0.03
Space Heat		71.7	2.41
Water Heat		25.3	0.85
SUBTOTAL		258.7	8.68
TOTAL	207633	2979	100.00

Heat Rate (kBTU/kWh) = 10.239

Sources: CEC 1991b, CEC 1990, Gough 1992, Atkinson 1992, Piette, Eto, and Harris 1991

Uncertainties in the Analysis

Since few of the technologies covered in this report have been commercialized, estimates of measure cost, savings, and commercialization date are generally imprecise.

Due to these limitations, in calculating CSE and savings potential ratings, figures were rounded to one significant digit -- finer distinctions would be meaningless. Furthermore, the data reported should be viewed as the midpoint of a range, with endpoints as much as 50% higher and lower than the midpoint.

However, many of the estimates are not so imprecise. In some cases data were obtained from several sources and there was general agreement between sources as to specific data values. Many of these cases included data obtained from independent analysts who do not have a vested interest in promoting a product. In cases that meet most of these criteria (designated by an "A" rating in the data quality field of the database), the range of likely values will generally be within 10-20% of the specific values listed.

In other cases, data were based on only preliminary estimates obtained from only one source, often a source with a vested interest in promoting the product. In these cases (designated by a "C" rating in the data quality field of the database), the range of likely values may be as much as 50% higher and lower than the specific values listed. In still other cases, solid estimates were obtained from one source, or less precise estimates from several sources. In these cases (designated by a "B" rating in the data quality field of the database) the range of likely values is between the two extremes discussed above.[2]

In addition, costs and savings will vary from application to application. The analyses described in this report are for "typical" applications; savings and costs are likely to be different for buildings that differ significantly from the average. This is particularly a problem when examining data on energy savings from heating and cooling measures. For climates that differ significantly from the typical California climate (approximately 2000 heating degree days and 1000-1500 cooling degree days [base 65° F]) savings will vary substantially than the values listed here.

Data Collection on Medium/High Priority Emerging Technologies

For each of the medium/high priority technologies, over 30 pieces of data were compiled for a database. Based on these values, as well as a review of published literature on each technology and telephone conversations with researchers and manufacturers working on the

[2] Three of technologies that fit into the "B" and "C" categories deserve special mention. The cool storage roof, indirect/direct evaporative cooling, and the combined refrigerator/water heater (technologies H4, H6 and W2) are all products in which the Davis Energy Group has an interest. Since the Davis Energy Group is one of the authors of this study, the other members of the project team took special care to review material on these technologies. Still, we wanted to acknowledge the potential for bias and hence we attempted to be conservative in assigning data quality ratings for these technologies.

different technologies, written descriptions of the technologies and their status and prospects were prepared. The database variables are as follows:

1. Technology number (Letter/number code shows end-use and sequential number for easy reference between report and database).

2. Technology name.

3. Technology description (a brief description of the technology; a fuller description is included in the report text).

4. Market sectors (RES, COM, IND, R&C, C&I, ALL).

5. End-use (CLODRY = clothes dryer; CLOWAS = clothes washer; COOK = cooking; COOL = cooling; DISH = dishwasher; FAN = fan; FREEZ = freezer; HC = heating and cooling; HEAT = heating; LIGHT = lighting; MOTOR = motor; OFFEQ = office equipment); REF = refrigeration; REFRZ = refrigerator/freezer; TSTAT = thermostat; VENT = ventilation; WH = water heating; WSH = water and space heating; OTH = other).

6. Appropriate market segments (RET = retrofit; NEW = new construction; ROB = replace on burnout; OEM = original equipment manufacturers, who incorporate technology into new equipment).

7a. Typical unit size (size used for analysis).
7b. Units for above (e.g., horsepower).

8. Base case description (a brief description of the existing technology to which the emerging technology is being compared).

9a. Base case efficiency.
9b. Units for above (e.g., EER).

10a. Base case energy use.
10b. Units for above (e.g., kWh).

11a. Emerging technology efficiency.
11b. Units for above (e.g., EER).

12a. Emerging technology energy use.
12b. Units for above (e.g., kWh).

13. Electricity savings achieved by emerging technology relative to base case (kWh/year).

14. Natural gas savings achieved by emerging technology relative to base case (therms/year).

15. Energy savings for typical unit (%). Where a technology affects both electric and natural gas use, the percentage reduction in energy use is based on source energy savings where a kWh of electricity is valued at 10,239 Btu.

16. Peak summer demand savings for typical unit -- kW (savings at time of summer peak -- 3 pm)

17. Peak winter demand savings for typical unit -- kW (savings at time of winter peak -- 7 pm).

18. Note on interactive effects (letter codes for how savings are likely to change when this technology is integrated into a package of measures -- these are summarized in Table 1-2).

19. Retail cost for typical unit once technology established (1992 $; for commercial sector technologies, costs are in quantities used in a medium-sized office/retail building).

20a. Other costs (other important costs included in the analysis; i.e., additional or avoided maintenance costs and additional or avoided operating costs such as water, detergent, or use of a secondary energy source).

20b. Units for above (per year or over life cycle).

21. Estimated date of commercialization (may be a range).

22. Estimated measure life (years). These are average installed lives in the field, not engineering lives in a laboratory.

23. Current status of technology (COMM = commercialized; FLDTEST = field test; PROTO = prototype; RES = research).

24. Estimate of technically feasible applications (approximate percentage of end-use applications for which this technology is likely to be appropriate). This figure does not take into account the likely commercialization date of the technology nor the rate at which the equipment or building stock turns over. These latter factors are incorporated into variable #27.

25. Data quality (good, fair, or poor).

26. Cost of saved energy (levelized cost of savings over measure lifetime; $/kWh or $/therm).

27. Savings potential -- percentage of energy used by California building in the year 2010. These are calculated as the product of the following factors (however, not all factors apply to all measures):

Table 1-2. Interactive Effects Codes (for variable #18).

<u>Code A</u>: HVAC bonus of 10-35% for internal load-dominated commercial buildings for internal gain reduction measures like lighting and office equipment improvements. In shell-dominated small commercial and residential buildings, HVAC bonus is probably negative nationally in cooler climate zones of California, but likely modestly positive in warmer climates.

<u>Code B</u>: External and internal gain control strategies (glazings, albedo, lights, office equipment) yield capital cost savings via downsizing of HVAC systems. In new design, the capital savings can sometimes be large enough to pay the marginal cost of the load reduction measures.

<u>Code C</u>: In new construction only, more rentable space and reduced structural requirements from downsized duct-work made possible by gain reduction measures. At ~$20/ft annual rent for commercial space, smaller ducts can yield very high benefits.

<u>Code D</u>: Advanced glazings provide both shell thermal benefits and greater use of daylighting, hence reduced need for electric lighting.

<u>Code E</u>: Integrated lighting retrofit package of ballasts, improved lamps, reflectors, and lenses may yield greater benefits than the sum of the parts. For example, a reflector alone will increase delivered light but its greatest benefit is to allow de-lamping, which in turn reduces heat buildup in fixture, which in turn improves performance of the lamps and perhaps lifetime of the ballast.

<u>Code F</u>: Integrated packages of measures may yield less total savings than the sum of the parts due to overlap; e.g., equipment improvement leaves less waste to be saved by better controls.

<u>Code G</u>: Improvements that reduce waste heat output by motors and office equipment not only reduce energy use and cooling loads, they probably increase the lifetime of the equipment since heat is a primary enemy of electronics and motor insulation.

<u>Code H</u>: Measures that reduce the volume and/or detergent loading of hot water use (in showers, sinks, laundries and dishwashing) also reduce wastewater treatment and pumping capacity requirements, thereby reducing the amount of energy and water used for wastewater treatment and pumping.

<u>Code I</u>: Measures that add heat to a space, thus reducing space heating load and increasing cooling load.

- o Proportion of California energy use in 2010 due to that end use.
- o Measure % savings.
- o Proportion of equipment stock that will turn over between 2010 and commercialization date (for replacement measures with lives greater than the turnover period).
- o Proportion of equipment stock that will be included in buildings constructed between 2010 and commercialization date (for measures that are only applicable in new construction).
- o % technically feasible (variable #24).

28. Recommended next steps (R&D = R&D support; DEM = demonstration projects; REB = utility rebate programs; GC = "Golden Carrot" type programs;[3] ED = educational efforts; STDS = minimum efficiency standards; OTH = other).

29. Notes (for important comments such as key assumptions made to calculate some of the above values; more extensive notes are included in the written report).

30. Sources -- author/contact name and date (full references are included in a section at the back of the report). Sources are listed separately for energy savings, cost, measure life and load shape.

31. Primary contact -- name and address where a single individual is the primary contact on a technology.

Copies of this database are available from the California Energy Commission.

ORGANIZATION OF THIS REPORT

The remainder of this report describes the findings of this project.

Chapter 2 includes approximately one page written summaries on each of the medium/high priority emerging technologies. These summaries describe the technology, its current status, likely costs, savings, and commercialization date, and recommended next steps for advancing the technology. In addition, this chapter includes tables on each technology which report the information in the database.

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[3] "Golden Carrot" programs are utility incentive programs that seek to encourage manufacturers to develop new equipment that is more efficient than the best products on the market. Examples of Golden Carrot programs are described in the writeups for technologies A1 and H1.

Chapter 3 contains brief descriptions (approximately one paragraph) of the lower priority emerging technologies.

Chapter 4 analyzes some of the trends which emerge from our research and identifies the XX technologies with the largest potential for cost-effective energy savings in California. This chapter also includes recommendations, with an emphasis on steps to advance the highest priority technologies.

Chapter 2

MEDIUM AND HIGH PRIORITY EMERGING TECHNOLOGIES

INTRODUCTION

This chapter contains written descriptions and data tables on each of the medium and high emerging technologies identified through the process described in Chapter 1. This chapter consists of a set of facing pages on each technology. The left-hand page contains a written summary on the technology. The right-hand page summarizes information on each technology as contained in the database compiled for this project. Technologies are ordered by end-use as follows:

1. Appliances.
2. Lighting.
3. Building shell.
4. Space heating and cooling.
5. Water heating.
6. Commercial refrigeration.
7. Motors.
8. Office equipment.
9. Miscellaneous.

A1. <u>"Golden Carrot" Refrigerator/Freezer</u>

New Federal efficiency standards for refrigerator/freezers (R/F) take effect in 1993. Under these new standards the average new refrigerator/freezer (equivalent to a 19 ft^3 automatic defrost unit with a top-mounted freezer and without through-the-door service) must consume less than 704 kWh annually. The Federal efficiency standards are scheduled to be revised again, effective 1998.

To encourage manufacturers to develop and market refrigerator/freezers that are substantially more efficient than the 1993 standards, and also to influence the Federal 1998 standards, a group of electric utilities has formed a consortium -- the Super Efficient Refrigerator Program. Inc. (SERP). In July of 1992 SERP issued a Request for Proposals to refrigerator manufacturers asking them to compete for a $30 million pot of incentive money (SERP, 1992a). Manufacturers bid on the basis of refrigerator efficiency and requested incentive. The manufacturer who promises the most energy savings at the lowest cost per kWh saved wins the entire pot. Incentives will be paid when refrigerators are delivered to retail stores. To be eligible, bids must be for units that contain no CFCs and that use less than approximately 500 kWh/year. Fourteen bids were submitted in October 1992, including a number of bids from major manufacturers. In December 1992, two semi-finalists were selected -- Frigidaire and Whirlpool. These manufacturers will build prototype units and submit them to SERP for testing. Based on the results of these tests, a single winner will be selected in June 1993. The two semi-finalist bids are for units that use 30-50% less energy than required under the 1993 federal efficiency standards. Units may reach retail stores as early as 1994 (SERP, 1992b). Manufacturers involved in the SERP program are not divulging details about their designs for proprietary reasons.

A variety of different technologies may be employed in the winning bid including improved compressors, heat exchange cycles, heat exchangers, gaskets, refrigerants, defrost cycles, and insulation. Many different design paths can lead to a unit using 30-50% less energy than 1993 federal requirements. Possibilities range from a refrigerator with thick walls to refrigerators using vacuum panel insulation to refrigerators using new-cycles such as the Lorenz cycle. A study by the U.S. Environmental Protection Agency (EPA, 1992a and 1992b) explores the options and their costs in detail.

Based on drafts of the EPA study, the requirements of the SERP program (SERP 1992a), and discussions with other industry experts, a unit using 40% less energy than the 1993 federal efficiency standards will cost an estimated $100 more than a unit that just meets the standards.

Many utilities, including most California utilities, are participating in the SERP program. Utilities that are not participating can offer consumer rebates for models that are as efficient as the winning SERP bid. Utilities that are participating can also offer consumer rebates after the incentive money they have channeled through SERP runs out.

A1. Golden Carrot refrigerator

SERP, Inc. RFP induces manufacturers to produce refrigerator using 40% less than NAECA requirements.

Market sectors:		RES
End-use:		REFFRZ
Market segment:		NEW, ROB
Typical unit size:		19 cf
Base case -		
Description: Unit @ 1993 NAECA levels		
Efficiency:		704 kWh/yr
Energy use:		704 kWh/yr
New technology -		
Efficiency:		422 kWh/yr
Energy use:		422 kWh/yr
Electricity savings:		282 kWh/year
Gas savings:		0 therms/year
Percent savings:		40%
Summer demand savings:		0.043 kW
Winter demand savings:		0.032 kW
Interactive effects:		A
Technology cost:	$	100 incremental
Other costs:	$	0
Commercialization date:		1995
Measure life:		19 years
Technically feasible applications:		100%
Data quality:		A
Cost of saved energy:	$	0.03/kWh
Savings potential:		1.6%
Current status:		RES, PROTO
Next steps:		REB
Notes:		

Sources - savings:	EPA 1992a; L'Ecuyer 1992; SERP 1992
cost:	EPA 1992a; L'Ecuyer 1992
load shape:	PG&E 1992a
measure life:	DOE 1989
other:	n/a
Principal contact:	none

A2. <u>200-300 kWh Refrigerator/Freezer</u>

This is an advanced refrigerator/freezer that includes additional efficiency measures beyond those included in the "Golden Carrot" refrigerator. To reduce annual energy consumption to the 200-300 kWh/year range will likely require vacuum panel insulation, separate compressors and/or condensers for the refrigerator and freezer compartments, variable speed compressor operation, and/or new refrigeration cycles.

One refrigerator on the market -- the custom-built Sun Frost RF-16 -- now achieves performance approaching these levels (e.g. 295 kWh/year for a 16 cubic foot model). But this model costs approximately $2000 and specific features of the design (small size, semi-defrost) limit its consumer appeal. The high cost is largely due to limited sales which are currently insufficient to justify use of mass production techniques (Wilson and Morrill, 1992).

A draft analysis by EPA (1992a) indicates that there are several viable technology options for reducing refrigerator/freezer energy use to these performance levels at reasonable cost and in ways that are likely to find consumer acceptance. These options make extensive use of existing technology, but some of the options may need components that have not been fully developed and tested, including low-infiltration gaskets (50% better than today's gaskets), new refrigerants, and vacuum panel and carbon black insulation. Based on preliminary figures from the EPA analysis (EPA 1992b), a 250 kWh/year refrigerator will cost an estimated $90 more than the "Golden Carrot" refrigerator. This price estimate is based on the incremental cost to the manufacturer plus a 50% markup between the manufacturer and retail level (a 50% markup on the incremental cost allows for some additional profit on the more efficient unit, but assumes competition between manufacturers keeps profits per unit to values only somewhat higher than those earned on current models). This price estimate is subject to substantial uncertainty.

Due to the work that will be required to perfect this model, availability is not expected until approximately the turn of the century. This performance level is likely to be beyond the requirements of 1998 federal efficiency standards. Inducement to reach this performance level is likely to come from utility rebates which build upon the 1998 federal standards, and/or as a result of still higher standards which are scheduled to be promulgated by DOE in 2000, and to take effect three years later.

The next step to developing these refrigerators is to begin building and testing prototype models that combine many of the features discussed above. In addition continued research on vacuum panel insulation, improved gasket design and new refrigerants and refrigerant cycles can also help to advance to this high level of overall efficiency.

A2. 200-300 kWh R/F

Additional improvements beyond Golden Carrot R/F including new cycles and insulation.

Market sectors:		RES
End-use:		REFFRZ
Market segment:		NEW, ROB
Typical unit size:		19 cf
Base case -		
Description: Golden Carrot refrigerator (technology A1)		
Efficiency:		422 kWh/yr
Energy use:		422 kWh/yr
New technology -		
Efficiency:		250 kWh/yr
Energy use:		250 kWh/yr
Electricity savings:		172 kWh/year
Gas savings:		0 therms/year
Percent savings:		24%
Summer demand savings:		0.026 kW
Winter demand savings:		0.020 kW
Interactive effects:		A
Technology cost:	$	90 incremental
Other costs:	$	0
Commercialization date:		2000-03
Measure life:		19 years
Technically feasible applications:		100%
Data quality:		C
Cost of saved energy:	$	0.04/kWh
Savings potential:		0.6%
Current status:		RES
Next steps:		R&D, DEM

Notes: % savings and savings potential relative to 704 kWh unit.

Sources -	savings:	EPA 1992a
	cost:	EPA 1992a
	load shape:	PG&E 1992a
	measure life:	DOE 1989
	other:	n/a
Principal contact:		none

A3. Advanced Freezer

Stand-alone freezers are present in only about 35% of U.S. homes. Furthermore, due to higher insulation levels, smaller size, and less frequent door openings, the typical stand-alone freezer uses 30-40% less energy than the typical refrigerator/freezer (DOE, 1989). Due to these factors, freezers account for only about 1% of California building energy use (see Table 1-1). Accordingly, improvements in freezers are largely driven by improvements in the much larger refrigerator/freezer market.

The advanced freezer model examined here is the technical equivalent of the "Golden Carrot" refrigerator. It will likely include increased insulation (either thicker walls or vacuum panel insulation) and higher efficiency compressors. Other energy-saving features may be employed as well.

Two recent analyses have examined the costs and savings that are possible with advanced freezer designs. One, a 1989 analysis by DOE, concluded that average freezer energy consumption could be reduced to 350 kWh/year at an incremental cost of $75 relative to a unit just meeting the 1993 federal efficiency standards. The second, an analysis by several environmental groups (Alliance to Save Energy, et al., 1992) concluded that freezer energy consumption could be reduced to 218 kWh/year at an incremental cost of $236. For this study, the average of these two cost and performance estimates was used.

The technologies to achieve these levels of performance are probably simpler than the technologies in the "Golden Carrot" refrigerator. However, since freezer sales are less than 25% of refrigerator sales, there is less incentive for manufacturers to develop these models. Accordingly, the estimated commercialization date is 1998 -- when the new federal efficiency standards are scheduled to take effect.

To advance this measure, prototypes need to be developed, perhaps with utility assistance. Utility rebates may also encourage manufacturers to develop these improved models.

A3. Advanced freezer

Efficient freezer contains improved compressor and insulation.

Market sectors:		RES
End-use:		FREEZ
Market segment:		NEW, ROB
Typical unit size:		14 cf
Base case -		
Description: Unit @ 1993 NAECA levels		
Efficiency:		526 kWh/yr
Energy use:		526 kWh/yr
New technology -		
Efficiency:		284 kWh/yr
Energy use:		284 kWh/yr
Electricity savings:		242 kWh/year
Gas savings:		0 therms/year
Percent savings:		46%
Summer demand savings:		0.037 kW
Winter demand savings:		0.028 kW
Interactive effects:		A
Technology cost:	$	172 incremental
Other costs:	$	0
Commercialization date:		1998
Measure life:		21 years
Technically feasible applications:		100%
Data quality:		B
Cost of saved energy:	$	0.06/kWh
Savings potential:		0.3%
Current status:		RES
Next steps:		GC, REB

Notes: Costs and savings based on average of values in analyses by DOE and ASE et al, expressed in 1992 $. Refrigerator/freezer load shape used to estimate peak savings.

Sources - savings:	DOE 1989; ASE 1992
cost:	DOE 1989; ASE 1992
load shape:	PG&E 1992a
measure life:	DOE 1989
other:	n/a
Principal contact:	none

A4. Horizontal Axis Clothes Washer

More than 95% of clothes washers in the U.S. are top-loading units that spin on a vertical axis. To wash clothes, the wash tub must be filled so that all clothes are covered. In Europe the dominant type of washer is the horizontal axis machine. Horizontal axis machines reduce hot water use by more than 50% because the washtub is only partially filled. With each rotation of the tub, clothes are dipped in the water at the bottom of the half filled tub. In addition, a variation on the horizontal axis design has been developed by the Italian firm Zanussi which pumps water from the bottom of the tub and sprays it over the top of the clothes. This system, which is sold in Europe and Asia, allows hot water use to be reduced still further because the spray allows clothes to stay wet with a smaller volume of water in the bottom of the tub.

Many horizontal axis units are front-loading machines, but some units sold in Europe are top-loading, consisting of a conventional top loading door and a second door in the rotating metal drum.

In addition to saving energy and water, horizontal axis machines may offer several other advantages. First, by eliminating the agitator, these units may create less wear and tear on clothes (however, some manufacturers dispute these claims). Second, they use less detergent -- approximately 66% less detergent than vertical axis machines. Third, they are not as prone to load imbalance problems that can plague some vertical axis machines (Lebot et al., 1990). Fourth, they may do a better job cleaning clothes than a vertical axis unit. One recent study conducted by Ontario Hydro compared the washing performance of a popular North American vertical axis machine to a popular European horizontal axis machine. The washing performance was consistently and significantly better for the European model (Edwards and Lithgow, 1991). Additional testing is needed with a larger number of machines before definitive conclusions about relative cleaning performance can be drawn.

In the U.S., only Frigidaire manufacturers a horizontal axis unit. This front-loader is sold under the Frigidaire, White-Westinghouse, Gibson, and Sears/Kenmore labels. In 1989 *Consumers Report* magazine reported that this unit needed repairs more often than conventional washers. About the same time Frigidaire decided to move its production facilities and temporarily stopped production. Models were slightly redesigned to deal with the repair problems and production resumed in 1992. Frigidaire is planning to actively market these machines with an environmental theme. No major redesigns (e.g. a top-loading model) are planned until the market acceptance of the current model can be assessed (Hughes, 1992).

Staber Industries, a washing machine reconditioning firm, has developed a top-loading horizontal axis machine that is the same physical size, and handles the same size load as a standard vertical axis machine. This machine has approximately half the parts of a conventional machine and features stainless steel inner and outer tubs. Staber expects that these features will increase unit reliability and lifetime. Some models of this machine will have a higher spin-speed than standard machines (the advantages of high spin-speed are described in the next section of this report). Prototypes have been built and tested. Staber is now raising capital to move into production and hopes to begin production in 1993. They plan to sell to distributors of coin-operated machines, selected retail outlets, and factory-direct shipments to "green consumers" (Staber, 1992).

Several other major appliance manufacturers are also reportedly working on developing horizontal axis units.

Concerns about horizontal axis washers include consumer acceptance, load capacity, and wash time issues. For example, the Association of Home Appliance Manufacturers (AHAM) commissioned a consumer preference study which indicated that many consumers found loading a top-loading, horizontal axis machine cumbersome and that adding clothes during the wash cycle was more difficult (ADL, 1991). The AHAM study was selective in the issues studied (for example, cleaning performance was not included), but these results indicate that further consumer research is needed. Load capacity is smaller for many European horizontal axis machines, but larger capacity units are available. For example the load capacity of the Staber machine -- 15 pounds -- will be larger than a standard vertical axis machine (14 lbs.) though smaller than a typical "large capacity" machine (18 lbs.). Wash times are generally longer for horizontal axis machines; for example, the Staber machine has a wash time of 48 minutes (Staber, 1992), nearly twice as long as a typical vertical axis machine. Researchers at other companies are reportedly working on ways to shorten horizontal axis wash times.

Analysis here is based on a horizontal axis machine that is either front- or top-loading. Savings are based on DOE estimates (1990) for a horizontal axis machine. Separate analyses are conducted for electric and gas hot water. A study commissioned by AHAM estimated that horizontal axis machines will, on average, cost $80 more to produce than vertical axis machines, resulting in a retail cost increase of $183 per unit assuming retailers add their normal markup to the manufacturer cost and further assuming that all direct and indirect costs related to the development of these machines are passed along to consumers. However, the AHAM study further noted that "it is very unlikely that washing machine manufacturers will be able to pass through more than actual materials cost increases" (ADL, 1991). A recent analysis by the Washington State Energy Office (Pope and Slavin, 1992), which included an informal dealer survey, estimated that horizontal axis machines will cost $175 more than an equivalent vertical axis machine. Discussions with manufacturers (Hughes, 1992; Staber, 1992) and other industry experts who asked to remain anonymous, also indicate an incremental cost of approximately $175 in the near-term. For purposes of this analysis, an incremental cost of $175 was assumed, although as more products enter the market, price reductions are likely.

In addition to purchase costs, other costs are also included in the analysis. Based on a study by Lawrence Berkeley Laboratory (Lebot et al., 1990), use of horizontal axis washers reduce annual detergent costs by $46 and water bills by $10.

Utilities can play an important role by testing and promoting new horizontal axis models now entering the market and by encouraging the development of prototype shower wash systems and other advanced designs. In particular, utilities can offer incentives to help sell models now entering the market and to encourage manufacturers to develop and commercialize additional units. These programs could be very timely as the U.S. Department of Energy will examine top-loading, horizontal axis machines for the upcoming 1999 clothes washer efficiency standard (DOE, 1990b). This rule-making is scheduled for completion in 1996.

A4a. Horizontal axis clothes washer -- electric water heat

Horizontal axis clothes washer with advanced features such as top loading and "shower washing".

Market sectors:		RES
End-use:		CLOWAS
Market segment:		NEW, ROB
Typical unit size:		14 lbs.
Base case -		
Description: Unit @ 1994 NAECA levels		
Efficiency:		1.77 kWh/cycle
Energy use:		674 kWh/yr
New technology -		
Efficiency:		0.69 kWh/cycle
Energy use:		262 kWh/yr
Electricity savings:		412 kWh/year
Gas savings:		0 therms/year
Percent savings:		61%
Summer demand savings:		0.056 kW
Winter demand savings:		0.076 kW
Interactive effects:		F, H
Technology cost:	$	175 incremental
Other costs:	$	-56 /year
Commercialization date:		1993
Measure life:		14 years
Technically feasible applications:		100%
Data quality:		A
Cost of saved energy:	$	-0.09/kWh
Savings potential:		0.5%
Current status:		COMM
Next steps:		REB

Notes: Other costs reflect lower detergent and water use of horizontal-axis washers. Analysis based on 380 cycles/yr. Electric dryer load shape used to estimate peak savings.

Sources -	savings:	DOE 1990a
	cost:	DOE 1990a, ASE 1992, Staber 1992, Hughes 1992, WASEO 1992, ADL 1991, Lebot et al. 1990
	load shape:	PG&E 1992a
	measure life:	DOE 1990a
	other:	DOE 1990a
Principal contact:		none

A4b. Horizontal axis clothes washer -- gas water heat

Horizontal axis clothes washer with advanced features such as top loading and "shower washing".

Market sectors:		RES
End-use:		CLOWAS
Market segment:		NEW, ROB
Typical unit size:		3 cf
Base case -		
Description: Unit @ 1994 NAECA levels		
Efficiency:		0.09 therms/cycle
Energy use:		33 therms/yr
New technology -		
Efficiency:		0.03 therms/cycle
Energy use:		12 therms/yr
Electricity savings:		42 kWh/year
Gas savings:		21 therms/year
Percent savings:		64%
Summer demand savings:		0.000 kW
Winter demand savings:		0.000 kW
Interactive effects:		F, H
Technology cost:	$	175 incremental
Other costs:	$	-56 /year
Commercialization date:		1993
Measure life:		14 years
Technically feasible applications:		100%
Data quality:		A
Cost of saved energy:	$	-1.9/therm
Savings potential:		1.4%
Current status:		COMM
Next steps:		REB

Notes: Other costs reflect lower detergent and water use of horizontal-axis washers. Analysis based on 380 cycles/yr. Electric savings valued at $0.06/kWh.

Sources - savings: DOE 1990a
cost: DOE 1990a, ASE 1992, Staber 1992, Hughes 1992, WASEO 1992, ADL 1991, Lebot et al. 1990
load shape: PG&E 1992a
measure life: DOE 1990a
other: DOE 1990a

Principal contact: none

A5. <u>High Spin Speed Clothes Washer</u>

The spin cycle in standard American clothes washers spins clothes at approximately 600 rpm, which reduces the moisture content of the load from 100% to approximately 50-75% (depending on fabric). Typically, this laundry is moved to a dryer, to reduce the moisture content to 2.5-5%. (Shepard et al., 1990; Lovett, 1981). However, a study by the National Institute of Science and Technology (NIST) found that to reduce moisture content of a typical laundry load from 70% to 40%, a spin cycle is approximately 70 times more energy efficient (requires 1/70th the energy) than a dryer thermal cycle. For 7 pound loads, increasing the spin speed to 900 rpm reduced dryer energy use by 28-47% depending on the fabric (Lovett, 1981).

High spin speeds are common in Europe, with many machines having spin speeds over 800 rpm, and some machines operating as high as 1500 rpm. To reduce wrinkling, these machines have complex cycles - slow spin, re-balancing, fast spin, and a final slow spin to ventilate the clothes. This type of variable speed operation is an ideal application for permanent magnet or switched reluctance motors, although other types of motors can also be used. High spin machines are also made in Japan (DOE, 1990a; Shepard et al., 1990).

In the U.S., the top-loading, horizontal axis machine now being developed by Staber Industries (described in section A4 of this report) has a top spin-speed of 700 rpm with approximately the same diameter tub as a standard U.S. clothes washer (water removal depends on both spin speed and tub diameter). The unit features a variable speed motor and drive which controls spin-speed. Staber has taken a load of clothes from a standard U.S. washer and put them through the spin cycle of their new unit. Additional water was removed; however, detailed measurements were not made (Staber, 1992).

One published report (ASE et al., 1992) estimates the cost of this measure at $100 per unit. Industry experts (who asked to remain anonymous) report a cost to manufacturers for this measure of approximately $60; adding to this the average retail markup (47% -- ADL, 1991) results in a retail price increase of $88. Based on these two estimates, an incremental cost of $95 is used in the analysis. However, if this measure were adopted along with other measures such as horizontal axis (A4) or direct drive washing machines (A13), the combined costs are likely to be lower than the sum of the individual measure cost estimates. Savings for electric and gas dryers are modeled separately and are based on the midpoint of the savings range found in the NIST study.

Several steps may be useful to advance this technology. First, the U.S. Department of Energy should revise official test procedures to include energy used by the dryer in the washer rating. Washers with higher spin speeds would receive better ratings. Second, additional prototype high spin speed washers are needed to demonstrate higher spin speeds than the Staber unit. Third, utilities can offer rebates or a Golden Carrot type program to encourage more manufacturers to bring these units to market.

A5a. High spin speed clothes washer -- electric dryer

High spin speed removes more water, leaving less water to be removed by dryer

Market sectors:		RES
End-use:		CLOWAS/CLODRY
Market segment:		NEW, ROB
Typical unit size:		6 cf dryer
Base case -		
Description: Unit @ 1994 NAECA levels		
Efficiency:		2.32 kWh/cycle for dryer
Energy use:		834 kWh/yr for dryer
New technology -		
Efficiency:		1.45 kWh/cycle for dryer
Energy use:		521 kWh/yr for dryer
Electricity savings:		313 kWh/year
Gas savings:		0 therms/year
Percent savings:		38%
Summer demand savings:		0.042 kW
Winter demand savings:		0.058 kW
Interactive effects:		F
Technology cost:	$	95 incremental
Other costs:	$	0
Commercialization date:		1995
Measure life:		14 years
Technically feasible applications:		100%
Data quality:		A
Cost of saved energy:	$	0.03/kWh
Savings potential:		0.9%
Current status:		COMM (in Europe)
Next steps:		DEM, REB
Notes:		Analysis assumes 359 cycles/yr.

Sources - savings:	Lovett 1981
cost:	ASE 1992, anonymous industry experts, ADL 1991
load shape:	PG&E 1992a
measure life:	DOE 1990a
other:	DOE 1990a
Principal contact:	none

A5b. High spin speed clothes washer -- gas dryer

High spin speed removes more water, leaving less water to be removed by dryer

Market sectors:		RES
End-use:		CLOWAS/CLODRY
Market segment:		NEW, ROB
Typical unit size:		6 cf dryer
Base case -		
Description: Unit @ 1994 NAECA levels		
Efficiency:		0.09 therm/cycle for dryer
Energy use:		33 therm/yr for dryer
New technology -		
Efficiency:		0.06 therm/cycle for dryer
Energy use:		21 therm/yr for dryer
Electricity savings:		-4 kWh/year
Gas savings:		12 therms/year
Percent savings:		38%
Summer demand savings:		0.000 kW
Winter demand savings:		0.000 kW
Interactive effects:		F
Technology cost:	$	95 incremental
Other costs:	$	0
Commercialization date:		1995
Measure life:		14 years
Technically feasible applications:		100%
Data quality:		A
Cost of saved energy:	$	0.8/therm
Savings potential:		0.2%
Current status:		COMM (in Europe)
Next steps:		DEM, REB
Notes:		

Sources - savings:	Lovett 1981
cost:	ASE 1992, anonymous industry experts, ADL 1991
load shape:	PG&E 1992a
measure life:	DOE 1990a
other:	DOE 1990a
Principal contact:	none

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A6. Automatic Clothes Washer Controls

The volume of water needed to wash and rinse clothes varies depending on the size of the load, the type of clothes, and how dirty the clothes are. In a typical washer, water quantities, temperature, and fabric type are selected by the user from a limited number of possible settings. Substantial energy and water could be saved if this choice was left to an automatic control system.

In Japan, Matsushita recently introduced a "fuzzy logic" machine that contains two optical sensors and special control circuitry to optically measure the transparency of the water and the rate at which it becomes turbid, judge the size of the load based on the strain on the motor, and respond by selecting one of approximately 600 cycle combinations. Fuzzy logic is a software system that allows the washer to make choices with a minimum of calculations (Shepard et al., 1990).

In the U.S., the Eaton Corporation has developed a prototype clothes washer that features fuzzy logic, a fill level sensor (to sense the height of the clothes and eliminate excess water use), a water temperature sensor (to limit the amount of hot water used), and a turbidity sensor (to sense the dirtiness of the wash and rinse water and adjust wash parameters accordingly). Eaton hopes to interest washer manufacturers in the control system (Bernhard, 1992).

Laboratory tests of automatic fill systems in the U.S. and Europe show 20% reductions in motor electricity and hot water use. Adding wash-water turbidity sensors may increase the savings substantially (Shepard et al., 1990). In addition, savings can be increased through use of a variable speed motor, where the fuzzy logic system selects the optimal motor speed for each point in the wash cycle.

While the energy savings from these controls are inviting, performance questions remain. Independent tests apparently are yet to be conducted on the accuracy of the sensors and controls, the cleaning performance of the machines, and the long-term reliability of the controls.

For the calculations, a fairly simple system is assumed with 20% energy savings. Eaton estimates this system will cost the manufacturer $35-40 per unit (Bernhard, 1992), resulting in a retail cost increase of approximately $55 (assuming a retail markup of 47% -- ADL, 1991). However, several manufacturers commented that this cost is low in their judgement (Harris, 1992; Hoffman, 1992), so for the analysis, the Eaton estimate was increased by 50%. This cost estimate is subject to substantial uncertainty.

Savings were analyzed separately for electric and gas water heaters. Only the electric analysis is reported here because the levelized cost per therm of gas saved is above the threshold ($1/therm) for inclusion as a medium priority technology.

The next step is to assess the performance and reliability of the systems and to refine cost estimates. Assuming results of these efforts are encouraging, utilities should consider rebates and/or Golden Carrot type incentives.

A6. Automatic clothes washer controls

Controls sense type of fabric, dirtiness of controls and other factors and adjust wash parameters accordingly.

Market sectors:		RES
End-use:		CLOWAS
Market segment:		NEW, ROB
Typical unit size:		14 lbs.
Base case -		
Description: Unit @ 1994 NAECA levels		
Efficiency:		1.77 kWh/cycle
Energy use:		674 kWh/yr
New technology -		
Efficiency:		1.42 kWh/cycle
Energy use:		539 kWh/yr
Electricity savings:		135 kWh/year
Gas savings:		0 therms/year
Percent savings:		20%
Summer demand savings:		0.018 kW
Winter demand savings:		0.025 kW
Interactive effects:		F, H
Technology cost:	$	83 incremental
Other costs:	$	0
Commercialization date:		1995
Measure life:		14 years
Technically feasible applications:		100%
Data quality:		B
Cost of saved energy:	$	0.06/kWh
Savings potential:		0.6%

Current status: C (in Europe and Japan)

Next steps: DEM, REB

Notes: Analysis assumes 380 cycles/yr. Electric dryer load shape used to estimate peak savings. Savings potential numbers include both electric and gas savings, despite questionable cost-effectiveness of gas savings.

Sources - savings: Shepard et al. 1990

cost: Bernhard 1992, ADL 1991, Harris 1992, Hoffman 1992.

load shape: PG&E 1992a

measure life: DOE 1990a

other: DOE 1990a

Principal contact: none

A7. Bubble-Action Washing Machine

In 1991, the Sharp Corporation began marketing their "Fully Automatic Bubble-Action Washing Machine" in Japan. Through the use of both scrubbing bubbles and advanced computer control, this washer reportedly results in cleaner clothes and lower water consumption (Levene 1993).

Bubbles forced from a nozzle located at the bottom of the washer circulate upward in vertical and horizontal swirling motions. Horizontal bubble swirls, generated by a computer-controlled pulsator on the bottom of the bin, help clean large wash loads or bulky items. Vertical bubble swirls prevent fabric damage when washing small loads or delicate fabrics. The bubble swirls replace the agitator found in conventional clothes washers. An advanced computer can analyze the wash load in various ways. For example, the computer can weigh the clothes and determine how much water and detergent is needed and how long the wash time should be.

According to Sharp, the bubble washing machine design cuts water usage by 30% per wash cycle and gets clothes about 20% cleaner than the typical washer. In addition, the machine operates almost silently. The technology is presently only available in Japan and Southeast Asia. Sharp Corporation has no plans to market the technology in the United States in the near future. The cost of the technology in Japan is roughly 20% more than the cost of a traditional washer (Levene 1993).

Approximately 90% of the energy consumed in a clothes washer is used to heat water, and the remaining 10% is consumed by the motor. Assuming hot water use is reduced by 30%, this results in a 27% reduction in total clothes washer energy consumption. The additional cost of the technology is estimated as the mid-point between a 20% increase in the cost of a typical Japanese washer ($133 in U.S. dollars) and a 20% increase in the cost of a typical U.S. washer ($86) (DOE 1990a, Levene 1993).

Savings were analyzed separately for electric and gas water heaters. Only the electric analysis is reported here because the levelized cost per therm of gas saved is above the threshold ($1/therm) for inclusion as a medium priority technology.

Due to the advanced computer feature of Sharp's Bubble-Action Clothes Washer, savings overlap with measure A6 -- Automatic Clothes Washer Controls. According to Sharp, approximately 80 % of the savings are due to the bubble-action feature and 20% to sensors and computer control (Yonskie, 1993). Additional testing of this unit is needed to verify energy consumption and cleaning performance. If these tests are encouraging, utilities should consider rebates or Golden Carrot incentives.

A7. Bubble-action washing machine

Scrubbing bubbles and advanced computer design cut water use by 30%

Market sectors:		RES
End-use:		CLOWAS
Market segment:		NEW, ROB
Typical unit size:		14 lbs.
Base case -		
Description: Unit @ 1994 NAECA levels		
Efficiency:		1.77 kWh/cycle
Energy use:		674 kWh/yr
New technology -		
Efficiency:		1.29 kWh/cycle
Energy use:		492 kWh/yr
Electricity savings:		182 kWh/year
Gas savings:		0 therms/year
Percent savings:		27%
Summer demand savings:		0.025 kW
Winter demand savings:		0.033 kW
Interactive effects:		F, H
Technology cost:	$	110 incremental
Other costs:	$	0
Commercialization date:		1998
Measure life:		14 years
Technically feasible applications:		100%
Data quality:		C
Cost of saved energy:	$	0.06/kWh
Savings potential:		0.8%

Current status: COMM (in Japan)

Next steps: F, REB

Notes: Analysis assumes 380 cycles/yr. Electric dryer load shape used to estimate peak savings. Savings potential numbers include both electric and gas savings, despite questionable cost-effectiveness of gas savings.

Sources -
- savings: Levene 1993
- cost: Levene 1993
- load shape: PG&E 1992a
- measure life: DOE 1990a
- other: DOE 1990a

Principal contact: Nancy Levene, Sharp Corp., Mahwah, NJ, (201) 529-8631.

A8. Microwave Clothes Dryer

This unit uses microwaves to heat and dry clothes, similar to the process microwave ovens use to warm food. Microwaves are more efficient than electric resistance heat (used in conventional electric clothes dryers) because by reacting with water molecules, microwaves add heat where the moisture is. Due to the high cost of electricity, this unit is more expensive to operate than a gas clothes dryer and hence is not a suitable replacement for gas dryers.

Several small manufacturers have been working since the mid-1980's to perfect this technology (Shepard et al., 1990). In 1990 EPRI began working with Maytag and Whirlpool on the technology. A prototype model was built in 1991 and field tests are planned for 1993. They hope for commercial models by 1994 (Kesselring, 1992) although other estimates place commercialization dates later (Thompson 1992).

Early models faced a problem with electrical arcing caused by metal in clothes such as zippers and snaps. However, research by several manufacturers solved the arcing problem -- switching over to electric resistance heat at the end of the drying cycle when clothes are nearly dry and the arcing potential is greatest (Johnson, 1992). Some technical problems still remain however. For example, small and thin objects that heat up rapidly, such as bobby pins left in pockets, could get hot enough to scorch fabrics (WSJ, 1992).

In addition to saving energy, the microwave dryer offers several other advantages including reduced wear on clothes and approximately 25% reduced drying times (Kesselring, 1992; Pesci, 1990).

Cost estimates for the microwave dryer vary enormously, from a low of about $30 more than conventional dryers (Shepard et al., 1990) to a high of $395 more (Harris, 1992). The midpoint of this range is $212. After reviewing this range of cost estimates, DOE (1990a) estimated that a microwave dryer will cost $143 more than a dryer that just meets the 1994 federal minimum efficiency standards. Researchers at Raytheon suggest that this measure will increase manufacturing costs by approximately $150, resulting in a retail price increase of approximately $225 (assuming a 50% markup to the retail level, in line with AHAM research for clothes washers -- ADL, 1991). Based on the midpoint and Raytheon estimates, an incremental cost of $225 is used in the analysis. This estimate is subject to substantial uncertainty.

Since several prototype models have been built and tested, the next step is a field test. As noted above, EPRI is planning such a test. When units reach the market, and if the cost of savings is less than utility avoided costs, utilities should promote them through rebates.

A8. Microwave clothes dryer

Dryer which uses microwaves instead of electric resistance heat.

Market sectors:		RES
End-use:		CLODRY
Market segment:		NEW, ROB
Typical unit size:		6 cf
Base case -		
Description: Unit @ 1994 NAECA levels		
Efficiency:		2.32 kWh/cycle
Energy use:		834 kWh/yr
New technology -		
Efficiency:		1.72 kWh/cycle
Energy use:		617 kWh/yr
Electricity savings:		217 kWh/year
Gas savings:		0 therms/year
Percent savings:		26%
Summer demand savings:		0.029 kW
Winter demand savings:		0.040 kW
Interactive effects:		F
Technology cost:	$	225 incremental
Other costs:	$	0
Commercialization date:		1995
Measure life:		17 years
Technically feasible applications:		79%
Data quality:		B
Cost of saved energy:	$	0.09/kWh
Savings potential:		0.5%
Current status:		RES, PROTO
Next steps:		DEM, REB

Notes: Only applicable to homes with electric dryers. Analysis assumes 359 cycles/yr.

Sources - savings:	DOE 1990a
cost:	DOE 1990a, Clausen 1992, Hoffman 1992
load shape:	PG&E 1992a
measure life:	DOE 1990a
other:	Kesselring 1992, DOE 1990a
Principal contact:	none

A9. Heat Pump Clothes Dryer

Heat pump clothes dryers use a refrigeration cycle to remove moisture from the exhaust air, then recirculate the dehumidified and rewarmed air (rewarmed using waste heat) back into the dryer. Relative to a standard electric resistance dryer, energy use is reduced by more than 60%. Thus, heat pump clothes dryers save significantly more energy than microwave clothes dryers (technology A8) (DOE, 1990a).

Heat pump clothes dryers for the industrial sector are now being marketed by the Nyle Corporation. Nyle has also developed a prototype residential unit in which they have modified a conventional electric dryer. The unit looks like a conventional dryer except that is contains the refrigeration system in the rear of the cabinet where the electric resistance heater usually goes. The closed loop design employed means the unit does not require an exhaust vent and thus does not have to be located along an outside wall. Due to elimination of energy waste through the exhaust vent, the heat pump can reach air temperatures similar to those reached in conventional electric dryers, allowing drying times to remain the same. The extension on the back of the dryer for the refrigeration system is approximately the same depth as a typical exhaust vent, and thus the dryer should fit in the same space as a conventional dryer. While the heat pump dryer does not require an exhaust vent, it does require a condensate drain. In most laundry rooms a clothes washer drain should be readily available (DOE, 1990a; Lewis, 1992). Since many clothes washers drain into laundry sinks, heat pump dryers may need to include condensate pumps to discharge into a sink.

While the energy savings from heat pump dryers are promising, the performance claims have yet to be verified by independent parties. The Electric Power Research Institute has commissioned a series of tests on a prototype unit which are scheduled to be completed in mid-1993 (Kesselring, 1992).

An even bigger issue facing heat pump clothes dryers is cost. Estimates by DOE and manufacturers (DOE, 1990a; Lewis, 1992; Hoffman, 1992) indicate that heat pump dryers will cost consumers approximately $300 more than conventional electric resistance dryers.

In addition to the incremental purchase cost, maintenance costs are likely to be higher. For the analysis, a $100 service call (1990 $) is assumed to be made midway during the dryer's 17 year life. The present value of this service call cost is incorporated, assuming a 5% real discount rate. These estimates are slight modifications of the assumptions used in the DOE analysis (DOE, 1990a).

The next steps to advance this technology are an independent assessment of performance, followed by a field test in consumer homes. If these tests of dryer performance and consumer acceptance prove successful, utilities can encourage commercialization of the technology by offering rebates or Golden Carrot incentives. Consumer education on the benefits of heat pump dryers will also be needed to overcome consumer resistance to the high initial purchase price.

A9. Heat pump clothes dryer

Dryer which uses heatpump instead of electric resistance heat.

Market sectors:		RES
End-use:		CLODRY
Market segment:		NEW, ROB
Typical unit size:		6 cf
Base case -		
Description: Unit @ 1994 NAECA levels		
Efficiency:		2.32 kWh/cycle
Energy use:		834 kWh/yr
New technology -		
Efficiency:		0.81 kWh/cycle
Energy use:		292 kWh/yr
Electricity savings:		542 kWh/year
Gas savings:		0 therms/year
Percent savings:		65%
Summer demand savings:		0.073 kW
Winter demand savings:		0.100 kW
Interactive effects:		F, I
Technology cost:	$	300 incremental
Other costs:	$	64 over lifecycle
Commercialization date:		1996
Measure life:		17 years
Technically feasible applications:		79%
Data quality:		B
Cost of saved energy:	$	0.05/kWh
Savings potential:		1.3%
Current status:		PROTO
Next steps:		DEM, GC

Notes: Only applicable to homes with electric dryers. Analysis assumes 359 cycles/yr. Other costs are a $100 maintenance call (discounted to present value) midway thru dryer life.

Sources - savings:	DOE 1990a
cost:	DOE 1990a, Lewis 1992, Hoffman 1992
load shape:	PG&E 1992a
measure life:	DOE 1990a
other:	DOE 1990a
Principal contact:	Don Lewis, Nyle Corporation, Bangor, ME, (800) 777-6953

A10. Low Water and Energy Use Dishwashers

DOE has set the 1994 minimum efficiency standard for dishwashers at 2.17 kWh/cycle for standard-capacity units (DOE, 1990a). Dishwashers now being produced in Europe and dishwashers scheduled for introduction by U.S. manufacturers indicate that dishwasher energy use can be reduced by approximately 25% below this standard, primarily by reducing water use.

European manufacturers are marketing highly-efficient models in the U.S., although these models are generally expensive. A.E.G.'s Favorit 665i consumes 20 liters of water and 1.6 kWh per cycle (Simpson, 1989). This model uses a spray system which activates the upper and lower spray arms alternately instead of simultaneously, thus reducing water use. Asea introduced their Asko 03 line into the American market in June 1992. This dishwasher uses approximately 20 liters of water and 1.5 kWh/cycle (Wasson, 1992). Although it has a 1400 W heating element, it uses less water than most models and therefore has reduced energy use. These dishwashers cost approximately $750 -- about twice as much as typical U.S. models.

Frigidaire plans to introduce their Ultra-Style Dishwashers in early 1993, many of which will consume approximately 2.0 kWh/cycle, 8% less from the 1994 standards (Patterson, 1992). The increased efficiency is due to an improved electronics package which programs wash cycles to reduce water consumption by 23% relative to previous models. A secondary feature is a new pump and filter system which aids in reducing water consumption.

KitchenAid has achieved improved efficiency in a just-released model by installing a smaller pump housing, a measure which reduces the water volume needed to protect the pump. Efficiency is reportedly similar to the Frigidaire model (Grunewald, 1992). Maytag also will be introducing a model with similar performance in early 1993 (George, 1992). Due to a variety of design changes incorporated into these new models, many of which do not relate to energy efficiency, all three manufacturers report that these new models will cost the same or less than the lower-efficiency models they replace.

One major manufacturer, wishing to remain anonymous, is planning a model with an efficiency of approximately 1.6 kWh/cycle. Energy savings will be achieved through further reductions in water consumption, although the manufacturer would not elaborate further on the features planned for this model for proprietary reasons. This incremental cost of this new model relative to comparable to 1993 models is expected to be "insignificant".

For the analysis, a model consuming 1.6 kWh/cycle was assumed, saving 26% relative to the 1994 standards. The incremental retail cost for this model was assumed to be $20. Savings are analyzed separately for electric and gas water heating.

One step needed to accelerate cost-effective efficiency improvements in the U.S. dishwasher stock is further demonstration of the washing performance of dishwashers which include a varying degree of energy-efficient features. Utility rebates for low water- and energy-use dishwashers would also assist in moving the market.

A10. Low energy and water use dishwashers -- electric water heat

Dishwasher ~25% more efficient than 1994 standards.

Market sectors:		RES
End-use:		DISH
Market segment:		NEW, ROB
Typical unit size:		8 place settings
Base case -		
Description: Unit @ 1994 NAECA levels		
Efficiency:		2.17 kWh/cycle
Energy use:		498 kWh/yr
New technology -		
Efficiency:		1.6 kWh/cycle
Energy use:		367 kWh/yr
Electricity savings:		131 kWh/year
Gas savings:		0 therms/year
Percent savings:		26%
Summer demand savings:		0.005 kW
Winter demand savings:		0.041 kW
Interactive effects:		F
Technology cost:	$	20 incremental
Other costs:	$	0
Commercialization date:		1995
Measure life:		13 years
Technically feasible applications:		100%
Data quality:		C
Cost of saved energy:	$	0.02/kWh
Savings potential:		0.3%
Current status:		PROTO
Next steps:		DEM, REB

Notes: Analysis assumes 229 cycles/yr. Peak impact based on load shape for electric ranges 2 hours before system peak.

Sources - savings:	Anonymous manufacturer
cost:	ACEEE based on discussions with manufacturers
load shape:	PG&E 1992a
measure life:	DOE 1990a
other:	DOE 1990a
Principal contact:	none

A10. Low energy and water use dishwashers -- gas water heat

Dishwasher ~25% more efficient than 1994 standards.

Market sectors:	RES
End-use:	DISH
Market segment:	NEW, ROB
Typical unit size:	8 place settings
Base case -	
Description: Unit @ 1994 NAECA levels	
Efficiency:	0.09 therm/cycle
Energy use:	20 therms/yr
New technology -	
Efficiency:	0.06 therm/cycle
Energy use:	13 therms/yr
Electricity savings:	0 kWh/year
Gas savings:	7 therms/year
Percent savings:	35%
Summer demand savings:	0.000 kW
Winter demand savings:	0 kW
Interactive effects:	F
Technology cost:	$ 20 incremental
Other costs:	$ 0
Commercialization date:	1995
Measure life:	13 years
Technically feasible applications:	100%
Data quality:	C
Cost of saved energy:	$ 0.3/therm
Savings potential:	0.5%
Current status:	PROTO
Next steps:	DEM, REB

Notes: Assume all savings are in reduced hot water use and that drying and motor energy use are identical to base model. Analysis assumes 229 cycles/yr.

Sources - savings: Anonymous manufacturer
cost: ACEEE based on discussions with manufacturers
load shape: PG&E 1992a
measure life: DOE 1990a
other: DOE 1990a
Principal contact: none

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A11. Low-Temperature Dishwashing Detergents

A move to eliminate environmentally-damaging phosphates and chlorines from automatic dishwashing detergents (ADDs), as well as child safety concerns related to high-alkaline ADDs, has led to the emergence of enzyme-based detergents. Enzymatic ADDs have the advantage of functioning more effectively at colder water temperatures than phosphate-based formulas. Test data indicate that the addition of enzymes to ADDs allows use of water 18° F cooler than that required by non-enzyme-based detergents, without lowering wash performance. In fact, evidence indicates that the combination of amylase (for starch breakdown), lipase (for fat breakdown), and protease (for protein breakdown) enzymes in one detergent can improve cleaning performance (Beckerich, 1992). Unfortunately, a representative of a U.S. enzymatic detergent manufacturer noted that they still recommend consumers wash at 140° F, which they thought was the lower end of the melting point of animal fat. The representative was surprised to hear that the limit is actually between 110 and 125° F (Biemer, 1983).

In the U.S. there are three enzyme-containing ADDs on the market: Amway's Crystal Brite, Shaklee's Basic D, and Benckiser's Electrosol (Petrowsky, 1992). These detergents are marketed for their environmental and safety benefits and not for potential energy-saving benefits. In fact, the manufacturers' recommended peak washing temperatures for these ADDs is no different than for other ADDs (Campra, 1992; Petrowsky, 1992).

U.S. consumers now wash their dishes at a peak temperature of approximately 140° F. Enzymatic ADDs could reduce peak temperatures to 122-130° F. In Europe, where enzymatic detergents are being used with greater frequency, a 131° F peak temperature is becoming more common (Bancroft, et al., 1991). Booster heaters, which raise water temperature by approximately 20° F, are a common dishwasher feature. Thus, the drop in peak temperature requirements allows central water heaters to be set at approximately 115-120° F considering pipe heat losses.

The typical California home now sets its water heater at 135° F, which results in an average temperature rise in the water heater of 75° F (DEG, 1992b). To be conservative, savings calculations assume that on average use of low temperature dishwashing detergents results in a 10° F reduction in hot water temperature (and not the 15-20° F reduction that is theoretically possible). As a further conservatism, reductions in standby losses from hot water tanks are also not considered.

In the U.S., enzymatic detergents have been estimated to cost 5-10% more than traditional ADDs (Bancroft, et al., 1991). Using the average cost of ADD at a local grocery store, $2.25 per 50 ounce container, the additional cost of using low-temperature detergent is $1.80 per dishwasher annually (assuming 229 loads per year, 2.3 ounces detergent per load, and 7.5% higher cost than traditional ADDs).

The important steps in furthering the use of low-temperature dishwashing detergents are to demonstrate the wash performance of enzyme-based detergents at various temperatures, and to educate consumers, detergent manufacturers, and dishwasher manufacturers on the potential to operate dishwashers at lower temperatures without sacrificing performance.

A11. Low-temperature dishwashing detergent -- electric water heat

Enzyme-based detergents function at low temp. to allow booster heaters to heat water to peak temp. of 130 degrees F.

Market sectors:		RES
End-use:		DISH
Market segment:		RET
Typical unit size:		8 place settings
Base case -		
Description: Hot water use for avgerage California household		
Efficiency:		4000 kWh/yr
Energy use:		4000 kWh/yr
New technology -		
Efficiency:		3467.00 kWh/yr
Energy use:		3467 kWh/yr
Electricity savings:		533 kWh/year
Gas savings:		0 therms/year
Percent savings:		13%
Summer demand savings:		0.019 kW
Winter demand savings:		0.17 kW
Interactive effects:		F, H
Technology cost:	$	1.80 incremental
Other costs:	$	0
Commercialization date:		1992
Measure life:		1 years
Technically feasible applications:		100%
Data quality:		A
Cost of saved energy:	$	0.00/kWh
Savings potential:		0.2%
Current status:		COMM
Next steps:		DEM, REB

Notes: Peak impact based on load shape for electric range.

Sources - savings:	Bancroft, et al. 1991; DEG 1992b
cost:	Bancroft, et al. 1991
load shape:	PG&E 1992a
measure life:	n/a
other:	DOE 1990a
Principal contact:	none

A11. Low-temperature dishwashing detergent -- gas water heat

Enzyme-based detergents function at low temp. to allow booster heaters to heat water to peak temp. of 130 degrees F.

Market sectors:		RES
End-use:		DISH
Market segment:		RET
Typical unit size:		8 place settings
Base case -		
Description: Hot water use for avgerage California household		
Efficiency:		230.00 therms/yr
Energy use:		230 therms/yr
New technology -		
Efficiency:		199.00 therms/yr
Energy use:		230 therms/yr
Electricity savings:		0 kWh/year
Gas savings:		31 therms/year
Percent savings:		13%
Summer demand savings:		0.000 kW
Winter demand savings:		0 kW
Interactive effects:		F, H
Technology cost:	$	1.80 incremental
Other costs:	$	0
Commercialization date:		1992
Measure life:		1 years
Technically feasible applications:		100%
Data quality:		A
Cost of saved energy:	$	0.1/therm
Savings potential:		0.2%
Current status:		COMM
Next steps:		DEM, REB
Notes:		

Sources - savings:	Bancroft, et al. 1991; DEG 1992b
cost:	Bancroft, et al. 1991
load shape:	PG&E 1992a
measure life:	n/a
other:	DOE 1990a
Principal contact:	none

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A12. Low-Powered Television Sets

Little data has been collected on the energy consumption of television sets in the U.S. A small study performed in the 1980s monitored the energy consumption of 54 televisions. Assuming an average television on-time of 2200 hours/year, the typical 19-20" television in this sample consumed 205 kWh/year (DOE, 1988). The most efficient television consumed 130 kWh/year. Although the study did not identify the particular design features leading to differences in energy use, the results indicate that significant improvements in the average efficiency of televisions are possible with currently available design options.

In 1988, DOE noted a number of design changes which would lead to improved efficiencies (DOE, 1988): (1) reduction in tuner standby power requirements; (2) installation of additional output taps in the power supply and replacement of the surge protector resistor with more efficient negative temperature coefficient resistors; (3) continuation of the ongoing energy-efficiency improvements of the cathode-ray tube (CRT). Electronic tuning requires memory to store the control settings when the set is turned off, drawing approximately 5 W of power. Replacing the resistance circuit in the tuner power supply with a transformer reduces the power requirements to 2 W. Changes in CRT design have led to recent reductions in energy use of 4-5%/yr, a rate expected to continue into the foreseeable future (Tannas, 1992).

Replacement of the standard CRT with low-powered liquid crystal display (LCD) screens has been considered for many years. However, a LCD-based television is presently five times more expensive than a CRT-based television. According to one industry expert, there is little likelihood that the cost differential will be significantly reduced by the year 2010 (Tannas, 1992). Other more energy-efficient display technologies face even greater barriers.

DOE estimates that reduced standby power requirements can save approximately 25 kWh/yr per set (assuming 1400 operating hours/year). An estimated savings of 8 kWh/yr will be achieved from jointly installing additional output taps and replacing the surge protector resistor. Adoption of these design changes as well as the 4.5% improvement in CRT efficiency lead to savings of 26% relative to the average consumption of the units monitored in the study described above. DOE estimates the retail cost of these improvements at $7/unit. DOE data are used in this analysis since no other sources of data are available. However, these data are very conservative and most likely underestimate the possible energy savings since models are already available which have lower energy consumption than this estimate. Calculations of the demand impacts of these measures were not possible since there are no available load-shape data for television sets.

Steps needed to advance these and other more advanced measures include: (1) testing and rating of the energy efficiency of each model on the market; (2) analysis of the efficiency range in the current television stock and identification of design features which lead to differences in efficiency; (3) DOE-established minimum efficiency standards for televisions.

A12. Low powered color TV

Improved efficiency TV as analyzed by DOE.

Market sectors:		RES
End-use:		TV
Market segment:		NEW, ROB
Typical unit size:		20 inch screen
Base case -		
Description: Average 1990 color TV		
Efficiency:		141 kWh/yr
Energy use:		141 kWh/yr
New technology -		
Efficiency:		116 kWh/yr
Energy use:		116 kWh/yr
Electricity savings:		25 kWh/year
Gas savings:		0 therms/year
Percent savings:		18%
Summer demand savings:		0.000 kW
Winter demand savings:		0 kW
Interactive effects:		A
Technology cost:	$	7 incremental
Other costs:	$	0
Commercialization date:		1991
Measure life:		11 years
Technically feasible applications:		100%
Data quality:		B
Cost of saved energy:	$	0.03/kWh
Savings potential:		0.3%
Current status:		COMM
Next steps:		STDS, OTHR
Notes:	Assumes 1400 hrs/yr on-time.	

Sources - savings:	DOE 1988; Tannas 1992
cost:	DOE 1988
load shape:	
measure life:	DOE 1988
other:	n/a
Principal contact:	none

L1. General Service Halogen IR

Halogen infrared reflector (IR) PAR and high wattage double-ended lamps have been commercially available for the past several years. The technology utilizes a thin film coating on the inside of the lamp surface which reflects 'wasted' infrared energy back onto the lamp filament, allowing the filament to burn hotter and thus increasing lamp efficacy.

GE currently produces 60 and 100W PAR 38 lamps, as well as 225, 350, and 900W double ended linear lamps for general lighting. They also produce a line of single-ended stage and studio lighting, including 350, 515, 650, and 660W lamps. The PAR and general lighting lamps are rated at 2000-3000 hour life, with shorter ratings on the stage and studio lamps due to their strict operating temperature/color parameters. Additionally, the light beam from the halogen IR lamp is cooler than that from a standard lamp, making it desirable for use in temperature-sensitive applications (Competitek, 1992). GE is currently working on a general service halogen IR lamp. A general service lamp would be shaped identical to a typical incandescent 'A' lamp. The general service lamps would employ a thin film coating on the halogen capsule to improve lamp efficacy.

The general service lamp efficacy would be equivalent to that of the infrared PAR versions currently available (McGowan, 1992). Therefore, a savings of approximately 27% over standard incandescent could be expected (Atkinson et al., 1992). LBL estimates a price range from $3 for commercial application to $7 for residential; for the purpose of this analysis, a standard $4 cost was used (Atkinson et al., 1992). A $1 per year credit for displaced standard incandescent lamp purchases is included in the analysis.

This lamp could potentially have far greater market penetration relative to the existing halogen IR lamps (due to the limited application of PAR and double-ended lamp types) and compact fluorescents (due to their cost, weight, and size). However, there are problems with the use of a standard lamp capsule because the filament tube is pressurized, thus currently requiring a thick outer shell. GE feels that they must eliminate the thick 'coke bottle' shell to reduce production costs to reasonable levels. Given these design problems, the date of release of this technology is uncertain but expected to be before 1996. GE states that research on this technology is not progressing as quickly as possible due to cuts in research and development budgets throughout the industry (McGowan, 1992). However, the technology is likely to be cost-effective in the residential incandescent retrofit market. Investment in R&D or Golden carrot incentives may help to bring the technology to market.

L1. General service halogen IR

GS halogen lamp with IR coating for higher efficiency

Market sectors:		ALL
End-use:		LIGHT
Market segment:		RET, ROB
Typical unit size:		1,150 lumens
Base case -		
Description: general service 'A' lamp		
Efficiency:		75 watts
Energy use:		75 kWh/yr
New technology -		
Efficiency:		55 watts
Energy use:		55 kWh/yr
Electricity savings:		20 kWh/year
Gas savings:		0 therms/year
Percent savings:		27%
Summer demand savings:		0.0020 kW
Winter demand savings:		0.0064 kW
Interactive effects:		A, B, C, F
Technology cost:	$	4 full
Other costs:	$	-1 /year
Commercialization date:		1995
Measure life:		4 years
Technically feasible applications:		80%
Data quality:		A
Cost of saved energy:	$	0.01/kWh
Savings potential:		1.2%
Current status:		RES
Next steps:		R&D, GC

Notes: Hrs./yr. usage=1000; other costs for displaced incan. lamp purchases

Sources -	savings:	Atkinson et al. 1992
	cost:	Atkinson et al. 1992
	load shape:	PG&E 1992a, PG&E 1992b
	measure life:	Atkinson et al. 1992
	other:	n/a
Principal contact:		Terry McGowan, GE, Cleveland, OH (216) 266-3234

L2. Coated Filament Incandescent

Research on improved incandescent lamp technologies is critical for several reasons. First, compact fluorescent lamp replacement of incandescents is not possible in all applications, given the size and weight of CFLs. Second, even with improvements in CFL size and weight, color-sensitive applications will still require incandescent illumination.

Improved filament design can allow standard incandescent lamps to burn hotter and thus more efficiently. A metal-oxide coating on the lamp filament would have low emissivity in the infrared spectrum and high emissivity in the visible spectrum, thus decreasing heat output and increasing light output. This technology would be extremely attractive in many color-sensitive applications, such as in art galleries. The light beam of the coated filament lamp would be cooler, thus reducing fading, food spoilage, etc. as well as the added benefit of reduced cooling loads. Lamp life is anticipated at 3500 hours; increased life is due to the strengthening of the filament.

Savings of approximately 65% are anticipated for this technology, relative to standard incandescent lamps. Thus, a 75W standard incandescent A lamp could be replaced with a 24W coated filament lamp with no loss of light output. With lamp costs estimated at $5 and a life of 3500 hours, a payback of less than one year can be expected with 1000 hours annual usage and $0.08/kWh costs (Atkinson et al., 1992). A $1 per year credit for displaced standard incandescent lamp purchases is included in the analysis.

Current research on this technology is strictly conceptual. Lamp manufacturers are not likely to begin development of the technology for several years, given current R&D priorities and shrinking budgets. Utility and/or government support for R&D could aid in the development and commercialization of the technology.

L2. Coated filament incandescent

Filament with low-E coating burns more efficiently.

Market sectors:		ALL
End-use:		LIGHT
Market segment:		RET, ROB
Typical unit size:		1,150 lumens
Base case -		
Description: standard 'A' lamp		
Efficiency:		75 watts
Energy use:		75 kWh/yr
New technology -		
Efficiency:		24 watts
Energy use:		24 kWh/yr
Electricity savings:		51 kWh/year
Gas savings:		0 therms/year
Percent savings:		68%
Summer demand savings:		0.00051 kW
Winter demand savings:		0.016 kW
Interactive effects:		A, B, C, F
Technology cost:	$	5 full
Other costs:	$	-1 /year
Commercialization date:		2000
Measure life:		4 years
Technically feasible applications:		95%
Data quality:		C
Cost of saved energy:	$	0.01/kWh
Savings potential:		3.6%
Current status:		RES
Next steps:		R&D

Notes: Hrs./yr. usage =1000; other costs for displaced incan. lamp purchases

Sources - savings:	Atkinson et al. 1992
cost:	Atkinson et al. 1992
load shape:	PG&E 1992a, PG&E 1992b
measure life:	Atkinson et al. 1992
other:	n/a
Principal contact:	Barbara Atkinson, LBL, Berkeley, CA (510) 486-7227

L3. Hafnium Carbide Single Crystal Whisker Filament Lamps

While compact fluorescent lamps offer an efficient alternative to standard incandescent lamps, their size, weight, color rendition, and cost often deter their use. Improvement in incandescent lamp filament design, however, affords an opportunity to increase efficacy and life of general service incandescent lamps while maintaining their original size, weight, and color rendering capabilities.

EPRI is currently sponsoring a project to determine the feasibility of utilizing hafnium carbide single crystal whiskers as filaments. Hafnium carbide single crystal whiskers are fibers of metal and ceramic with a markedly higher melting point than standard tungsten filaments, allowing for higher lamp operating temperatures and thus increased light output per watt. The fiber strength also would result in longer lamp life.

Energy savings from this improvement in filament design are anticipated to be 50%, although theoretical work on the technology indicates savings potential closer to 65%. For the purposes of this analysis, the estimated cost for a coated filament lamp was used. Both technology costs are very uncertain at the present time. A $1 per year credit for displaced standard incandescent lamp purchases is included in the analysis.

EPRI's contractor, Super Kinetics, Inc. of Santa Fe, will produce and test prototype lamps with hafnium carbide single crystal whisker filaments and publish their results in 1993 (EPRI, 1992). If the lamps are shown to be as efficient and reliable as the preliminary research indicates, utilities should consider offering a Golden Carrot type program to lamp manufacturers to encourage the commercialization of the technology.

L3. Hafnium carbide single crystal filaments

Improved filament burns more efficiently.

Market sectors:		ALL
End-use:		LIGHT
Market segment:		RET, ROB
Typical unit size:		1,150 lumens
Base case -		
Description: standard 'A' lamp		
Efficiency:		75 watts
Energy use:		75 kWh/yr
New technology -		
Efficiency:		38 watts
Energy use:		38 kWh/yr
Electricity savings:		38 kWh/year
Gas savings:		0 therms/year
Percent savings:		50%
Summer demand savings:		0.00038 kW
Winter demand savings:		0.012 kW
Interactive effects:		A, B, C, F
Technology cost:	$	5 full
Other costs:	$	-1 /year
Commercialization date:		1995
Measure life:		4 years
Technically feasible applications:		95%
Data quality:		C
Cost of saved energy:	$	0.02/kWh
Savings potential:		2.6%
Current status:		RES
Next steps:		R&D, GC

Notes: Hrs./yr. usage =1000; other costs for displaced incan. lamp purchases

Sources - savings:	EPRI 1992
cost:	n/a
load shape:	PG&E 1992a, PG&E 1992b
measure life:	EPRI 1992
other:	n/a
Principal contact:	Larry Ayers, EPRI Lighting Info. Office, Oakland, CA (800) 525-8555

L4. <u>100W Equivalent Screw-in Fluorescent</u>

The size and weight of the higher wattage compact fluorescent lamps (CFLs) often renders retrofit of existing incandescent fixtures impossible. Manufacturers including Osram and Philips have developed smaller 'triple tube' CFLs for the high wattage incandescent retrofit market. Beacon Light Products of Idaho is developing a 100W equivalent prototype with an alternative ballast design. Intersource Technologies, Inc. has also introduced their 'E-lamp' with a similar shape and size as incandescent A lamps and energy savings approaching CFLs.

The 23W Osram DULUX EL N lamp has been commercially available in Europe since 1990, and U.S. distribution began in the fall of 1992. This lamp is rated at 1500 lumens (initial), thus approaching the approximately 1,700 lumen range of a standard 100W incandescent (Osram, 1992). The lamp measures 178 mm long including the base, exceeding the 113-133 mm length of a standard 100W A lamp (IES, 1989). The 23W Philips SL-S Earth Light became commercially available in the US in the fall of 1992. This lamp is rated at 1550 lumens (initial) with a total length of 157 mm. Both the Philips and Osram lamps have a color rendering index (CRI) of 82 and a 10,000 hour rated life (Philips, 1992). The Beacon Light Products prototype is approximately 157 mm long, and is also rated at approximately 1,500 lumens. All the compact fluorescent lamps are currently being designed as integral units, i.e. the lamp and ballast are inseparable (Competitek, 1992).

Intersource Technologies, Inc. and American Electric Power Company, Inc. jointly announced a new type of compact lamp, known as the E-lamp, in June 1992. The lamp operates with a magnetic coil emitting a high-frequency radio signal (as opposed to electrodes in a standard fluorescent lamp) to ionize lamp gases which strike the phosphor coating on the lamp wall, reradiating in the visible light range. The lamp efficacy ranges from 50 to 65 lumens per watt, thus slightly lower than high wattage CFLs with electronic ballasts. Intersource's prototype lamp can fit a standard socket and is sized comparably to a standard A lamp. It has a CRI rating in the low 80's, again comparable to a CFL. However, the E-lamp has a rated life twice that of a CFL at 20,000 hours, due to the elimination of the electrodes. The E-lamp can also be dimmed as low as 5% of full output, and can operate at lower temperatures than CFLs (Narel, 1992). Independent tests showed that the lamp meets all federal requirements relative to radio wave distribution, allaying earlier concerns about radio wave interference (Cox, 1992).

The lamp will be jointly distributed by Intersource and MagneTek beginning in mid-1993. They will initially produce 24W A-line lamps, comparable to incandescent A lamps, and 24W R-line lamps, similar to incandescent reflector lamps. Both lamps are rated at 1200 lumens (roughly equivalent to a 75W incandescent), and thus are at the lower end of the 50-65 lumens per watt efficacy range. A 150W incandescent equivalent is currently in development (Cox, 1992). The high wattage CFLs cost between $25-30 retail (Philips, 1992). Prices for the E-lamp are anticipated to be $20-$25 (Cox, 1992).

Market acceptance of all of the above lamps could be accelerated by being incorporated into existing lighting rebate programs, possibly at higher rebate levels than those currently available for smaller wattage CFLs due to their higher initial cost. However, Intersource's high profile publicity campaign for the E-lamp may accelerate its acceptance, particularly in the residential sector. The company's survey of consumers showed that approximately 50% of consumers would "be tempted to buy" the lamp once it is available (Cox, 1992).

L4. Equivalent 100W screw-in fluorescent

Smaller CFL/'E' lamp with light output=100W incan.

Market sectors:		ALL
End-use:		LIGHT
Market segment:		RET, ROB
Typical unit size:		1,550 lumens
Base case -		
Description: standard 'A' lamp		
Efficiency:		90 watts
Energy use:		90 kWh/yr
New technology -		
Efficiency:		23 watts
Energy use:		23 kWh/yr
Electricity savings:		67 kWh/year
Gas savings:		0 therms/year
Percent savings:		74%
Summer demand savings:		0.00067 kW
Winter demand savings:		0.021 kW
Interactive effects:		A, B, C, F
Technology cost:	$	18 full
Other costs:	$	-1 /year
Commercialization date:		1992
Measure life:		10 years
Technically feasible applications:		26%
Data quality:		A
Cost of saved energy:	$	0.02/kWh
Savings potential:		1.1%
Current status:		COMM
Next steps:		REB, ED

Notes: 26% adj. for % of 100W/all incan.; 1000 hrs./yr. usage; other costs for displaced incan. lamp purchases

Sources - savings:	Osram 1992, Philips 1992
cost:	Osram 1992, Philips 1992
load shape:	PG&E 1992a, PG&E 1992b
measure life:	Philips 1992
other:	n/a
Principal contact:	none

L5. Compact Fluorescent Floor and Table Lamps

The size and weight of screw-in CFLs often prohibit their use in standard incandescent residential floor and table lamps. To address this problem, several small companies have begun to manufacture residential floor and table lamps designed for use only with compact fluorescent lamps. However, large residential fixture manufacturers have shied away from making CFL-dedicated fixtures, due to the high cost of CFLs when purchased retail. For example, GE has been trying to recruit residential fixture manufacturers to make and sell CFL fixtures with no success (McGowan, 1992).

The Fred Davis Corporation in Massachusetts is currently manufacturing and selling off-the-shelf fixtures equipped with 22W quad lamps, as well as producing fixtures with a variety of wattages on a made-to-order basis. The fixtures are designed to be aesthetically pleasing with traditional residential designs while incorporating CFL lamps exclusively for energy efficiency (Davis, 1992).

Mitor Industries of Mankato, MN has a tabletop luminaire, which can be converted to a floor fixture, with an internal hardwired ballast. The unit will be commercially available in January 1993. Three magnetic or one electronic ballast can be used with three 13W CFLs to provide the equivalent lumens of a 60, 100, and 150W incandescent fixture with one, two, or three lamps operating, respectively. The fixture is also available with three 9W lamps. The electronic ballast system has low harmonic distortion (approximately 8%) and a high power factor (approximately .98). The company expects higher demand for the electronic ballast system because of the instant start feature, which closely resembles incandescent fixtures. The fixture comes in commercial and residential models, with a theft-resistance option on the commercial unit. The company is considering producing single lamp fixtures with 18 and 26W quad lamps in the future (Johnson, 1992).

The Davis Corporation 22W lamps are priced mid-range for residential fixtures, around $120 (Davis, 1992). The Mitor fixture consumes approximately 45W with all three 13W lamps operating. Their luminaires are available in 10 different models with various prices, but range from $35-45 more than their incandescent counterparts (Johnson 1992). A $1 per year credit for displaced incandescent lamp purchases is included in the analysis.

Given the difficulty of using screw-in CFLs in standard incandescent residential floor and table lamps, as well as the concern over permanency of screw-in CFL applications, this technology should be promoted. These lamps could be marketed to residential consumers as 'environmentally-friendly' lights, worth the cost increase over a low-cost fixture. Utility rebate programs should provide incentives for these fixtures.

L5. Compact fluorescent floor & table lamps

Residential models designed for CFLs only.

Market sectors:		RES
End-use:		LIGHT
Market segment:		NEW, ROB
Typical unit size:		1,550 lumens
Base case -		
Description: standard 'A' lamp		
Efficiency:		90 watts
Energy use:		90 kWh/yr
New technology -		
Efficiency:		25 watts
Energy use:		25 kWh/yr
Electricity savings:		65 kWh/year
Gas savings:		0 therms/year
Percent savings:		72%
Summer demand savings:		0.0065 kW
Winter demand savings:		0.021 kW
Interactive effects:		A, B, C, F
Technology cost:	$	40 incremental
Other costs:	$	-1 /year
Commercialization date:		1992-1994
Measure life:		20 years
Technically feasible applications:		25%
Data quality:		A
Cost of saved energy:	$	0.03/kWh
Savings potential:		0.5%
Current status:		COMM
Next steps:		ED, REB

Notes: Operating 1000 hrs./yr.; other costs for displaced incan. lamp purchases

Sources - savings:	Davis 1992
cost:	Johnson 1992
load shape:	PG&E 1992a
measure life:	n/a
other:	n/a
Principal contact:	none

L6. Dimmable Compact Fluorescents

Several manufacturers have recently developed dimmable ballasts to operate compact fluorescent lamps (CFLs). Four-pin CFLs which can be dimmed, given an appropriate ballast, have been available for several years. Dimmable CFLs will increase potential incandescent retrofits in commercial buildings by permitting CFL use in display areas, lecture halls, and other areas requiring dimming capabilities. Manufacturers state that CFL dimming can be accomplished with only small losses in lamp efficacy and power factor.

Lutron has a solid state dimming adaptor coupled with an Advance electromagnetic ballast for operation of 18W or 26W Osram CFLs at 277V or 120V. The system can dim to 10% of lamp light output. Standard wall switch controls are available, as well as customized panel control systems which can be interfaced with an energy management system (Jones, 1992). ETTA recently introduced dimming electronic ballasts for use with high wattage (18-28W) CFLs. These units can dim to 5-10% of lamp light output while maintaining a power factor >90% (ETTA, 1992). Both these systems have hardwired ballasts, and therefore are being primarily marketed for new construction. No screw-in dimmable CFL systems are currently available and none are expected soon (Competitek, 1992).

A start-up company in Minneapolis, First Lighting Inc., is developing a centrally powered dimmable CFL system for new construction. The system consists of a central inverter to change 60Hz line frequency to 28KHz and a central dimmer, both of which can control up to 30 CFL/ballasts. The lamps can be dimmed to a minimum of 10%. The company has a working prototype, but must make final design modifications before production. They are currently in preliminary negotiations with two fixture manufacturers to license the product (Slater and Marks, 1992).

The Lutron dimming capability costs approximately $150 per luminaire above the cost of the fixture (Jones, 1992). The ETTA ballast is approximately 30% more expensive than standard CFL ballasts (Competitek, 1992). The First Lighting system costs are currently uncertain, but are anticipated to be 20-30% higher than incandescent dimming systems (Slater and Marks, 1992). Energy savings from all the systems are dependent upon user behavior; power consumption decreases linearly with dimming. This analysis used a 30% cost increase over an average CFL ballast cost and estimated savings at 72% (based upon conversion of an incandescent dimming system to a fluorescent dimming system with identical on/dim/off schedules). Potential applications were estimated at 10% of current incandescent loads based upon our estimated proportion of incandescent applications which utilize dimming. A $1 per year credit for displaced incandescent lamp purchases is included in the analysis.

Given that the technology is being marketed primarily to new construction, market penetration for appropriate applications/facilities should not be difficult once the technology is proven to building designers and owners. However, installation costs will be 20-30% higher than incandescent dimming systems; inclusion of the technology in utility lighting rebate programs should help to increase market acceptance.

L6. Dimmable compact fluorescents

CFL and dimmable ballast system

Market sectors:		R&C
End-use:		LIGHT
Market segment:		NEW
Typical unit size:		1,550 lumens
Base case -		
Description: standard 'A' lamp		
Efficiency:		90 watts
Energy use:		135 kWh/yr
New technology -		
Efficiency:		25 watts
Energy use:		38 kWh/yr
Electricity savings:		98 kWh/year
Gas savings:		0 therms/year
Percent savings:		72%
Summer demand savings:		0.093 kW
Winter demand savings:		0.093 kW
Interactive effects:		A, B, C, F
Technology cost:	$	29 incremental
Other costs:	$	-1 /year
Commercialization date:		1992
Measure life:		20 years
Technically feasible applications:		10%
Data quality:		A
Cost of saved energy:	$	0.01/kWh
Savings potential:		0.4%
Current status:		COMM
Next steps:		REB

Notes: Operating hrs./yr.=1500; other costs for displaced incan. lamp purchases

Sources - savings:	Jones 1992
cost:	Competitek 1992
load shape:	PG&E 1992a, PG&E 1992b
measure life:	n/a
other:	n/a
Principal contact:	none

L7. Fluorescent Surface Wave Lamp

At frequencies above 10 megahertz, fluorescent lamps can operate without electrodes; present lamps operate at lower frequencies and hence require electrodes. Significant energy losses are associated with electrodes, the most serious occurring in the compact versions. Electrodes also severely limit lamp life. In principle, high frequency electrodeless fluorescent lamps should allow major energy efficiency improvements and a tripling of lamp lifetime. Two important technical barriers must be overcome for commercialization to occur. These are keeping electromagnetic emissions to acceptable levels and developing a highly efficient radio frequency power conditioning system able to convert 60 Hz power to the operating frequency of the lamp.

A Philips electrodeless lamp-ballast system has been commercially available in Europe for approximately one year, and is expected to be introduced in the US in the first quarter of 1993 strictly on an original equipment manufacturer (OEM) basis. The system operates with a charge from a generator to excite the lamp gases, which displaces the standard electrodes in fluorescent lamps. The lamps are expected to last at least 60,000 hours due to elimination of the electrodes, the most common reason for fluorescent lamp failure (Berman, 1992).

The Philips system is rated at 85W total (two 4' lamps and ballast) with a light output of 5,500 lumens, thus roughly equivalent in efficacy to CFLs and lower than a standard 4 foot F40T12 lamp and electronic ballast system (Middlebrook, 1992). The system cost is several times higher than standard fluorescents. Philips is marketing the product strictly for exterior applications and "hard-to-reach" locations in particular, as maintenance savings from the system's long life are an attractive feature. Given its efficiency, the system is not an energy saver; however, it does serve as a preliminary step toward commercializing a technology which when refined does offer significant energy savings (Verderber, 1992).

Lawrence Berkeley Laboratory is working on a number of approaches to achieve a more efficient fluorescent lamp that can operate at the allowed frequencies of 13.56, 27 and 40 MHz. They estimate improvements of 20% and possibly higher values relative to T8 lamps and electronic ballast systems. However, it is expected that such a system is at least five years away from commercialization (Verderber, 1992). A $25 incremental cost and $6 lifecycle cost credit for displaced fluorescent lamp purchases were included in the analysis.

Further support of R&D on the LBL system could produce a widely applicable, cost-effective fluorescent system alternative. However, technological barriers do exist, and therefore increased funding is not certain to shorten the time period before market introduction.

L7. Fluorescent surface wave lamp

VHF ballast (60MHz) runs electrodeless lamp.

Market sectors:		C&I
End-use:		LIGHT
Market segment:		ROB, NEW
Typical unit size:		1 2 lamp 4' fixture
Base case -		
Description: T8 lamps w/ electronic ballast		
Efficiency:		60 watts
Energy use:		210 kWh/yr
New technology -		
Efficiency:		36 watts
Energy use:		126 kWh/yr
Electricity savings:		84 kWh/year
Gas savings:		0 therms/year
Percent savings:		40%
Summer demand savings:		0.071 kW
Winter demand savings:		0.048 kW
Interactive effects:		A, B, C, E, F
Technology cost:	$	25 incremental
Other costs:	$	-6 over lifecycle
Commercialization date:		2002
Measure life:		20 years
Technically feasible applications:		80%
Data quality:		B
Cost of saved energy:	$	0.02/kWh
Savings potential:		1.3%
Current status:		PROTO
Next steps:		R&D

Notes: Hrs./yr.=3500; other costs for displaced fluor. lamp purchases

Sources - savings:	Verderber 1992
cost:	Verderber 1992
load shape:	PG&E 1992a, PG&E 1992b
measure life:	Verderber 1992
other:	n/a
Principal contact:	Rudy Verderber, LBL, Berkeley, CA (510) 486-6398

L8. DC Lighting System

DC lighting systems operate by converting 3-phase AC power to DC, which is in turn transmitted through building-wide DC wiring to individual fixture inverters which convert DC power back to AC to operate lamps. The inverters substitute for ballasts in standard fluorescent systems. The system was developed at Brigham Young University, and is currently being produced by SENERGY Lighting Systems, Inc. of Nevada and marketed by Topaz Energy Systems of Salt Lake City (Competitek, 1992).

Test installations of whole-building DC lighting systems are currently in place at Brigham Young University and the Nebo School District, both in Utah. The Oregon Department of Energy has also promoted test installations, and recently completed the Professional 100 building in Salem. The 27,000 square foot building has approximately 0.7 watts/square foot lighting load with almost no harmonic distortion and high power factor. Standard T8 lamps and occupancy sensors were used in the installation. Monitoring to verify energy consumption is ongoing, but initial testing indicates lighting levels approximately 3% above design with energy consumption at predicted levels. The Oregon DOE is seeking further demonstration projects to promote the technology (Stevens, 1992).

The systems are also being marketed for retrofit installations. The manufacturer claims that the systems have higher reliability than standard fluorescent systems and increase lamp life by as much as four times normal levels (Competitek, 1992).

DC lighting systems can result in approximately 15% energy savings as compared to T8 and electronic ballast fluorescent systems with slightly higher installation costs as compared to standard AC systems in new facilities (Competitek, 1992). A $20,000 additional cost is estimated for the DC system in a typical new 50,000 square foot building. A $14,000 lifecycle cost credit for two displaced fluorescent lamp replacement cycles over the 15 year measure life was assumed for this analysis.

If DC systems prove as cost-effective and reliable as stated by the manufacturer and demonstrated in the test installations, utilities should consider sponsoring demonstration projects and offering incentives to promote use of the technology. The Oregon DOE stated that there were problems with certification of their test installation facility due to the lack of knowledge of the system by building inspectors, thus indicating a need for further education on the technology.

L8. DC lighting system

Building transformer for DC-powered fluor.

Market sectors:		C&I
End-use:		LIGHT
Market segment:		NEW
Typical unit size:		100,000 W (load for entire building)
Base case -		
Description: 50,000 s.f. bldg. w/T8 lamps & elec. ballasts		
Efficiency:		100000 watts
Energy use:		350000 kWh/yr
New technology -		
Efficiency:		85000 watts
Energy use:		297500 kWh/yr
Electricity savings:		52500 kWh/year
Gas savings:		0 therms/year
Percent savings:		15%
Summer demand savings:		45 kW
Winter demand savings:		30 kW
Interactive effects:		A, B, C, F
Technology cost:	$	20000 incremental
Other costs:	$	-14000 over lifecycle
Commercialization date:		1994
Measure life:		20 years
Technically feasible applications:		80%
Data quality:		B
Cost of saved energy:	$	0.01/kWh
Savings potential:		0.5%
Current status:		FLDTEST
Next steps:		DEM

Notes: Base=fluor. loads only; 29% new commercial stock; 3500 hrs./yr. usage; other costs for displaced fluor. lamp purchases

Sources - savings:	Competitek 1992
cost:	Competitek 1992
load shape:	PG&E 1992b
measure life:	Stevens 1992
other:	Stevens 1992
Principal contact:	Charlie Stevens, Oregon DOE, Salem, OR (503) 378-4040

L9. Scotopic Lamp

Scotopically enhanced lamps use phosphors to create a spectral distribution which allows optimal visual perception by the eye. The principle suggests that by changing the spectrum of light, illumination levels could be lowered from the values presently used without any degradation of visual quality. Scotopic distribution thus differs from the distribution used for lumen measurements. This principle is still controversial, in that it challenges the validity if the standard lumen as a measure of light output.

Lawrence Berkeley Laboratory has began research on the technology. GE has built prototype lamps based upon the LBL research, but has no current plans to market the product (McGowan, 1992). Philips has also looked at the technology, but has no plans for development until further research is completed (Lally, 1992).

Savings of 15-25% are anticipated as compared to standard T8 and T12 lamp systems, respectively. Lamp costs are anticipated to be between $5-6, roughly $2-3 higher than T8 lamps. Scotopic lamp applicability was limited to new construction for the purposes of this analysis; retrofit applications would be limited because to achieve both energy savings and good light distribution in retrofit applications will generally require changing fixture layouts. There are currently no estimates of dates for commercialization (LBL, 1992). Additional research, as well as demonstration projects, could help to advance the technology.

L9. Scotopic lamp

Fluor. lamp with higher scotopic content

Market sectors:	C&I
End-use:	LIGHT
Market segment:	NEW
Typical unit size:	5,800 lumens
Base case -	
Description:	2 lamp T8/electronic ballast fixture
Efficiency:	95 lumens/watt
Energy use:	210 kWh/yr
New technology -	
Efficiency:	123 equivalent lumens/watt
Energy use:	179 kWh/yr
Electricity savings:	32 kWh/year
Gas savings:	0 therms/year
Percent savings:	15%
Summer demand savings:	0.027 kW
Winter demand savings:	0.018 kW
Interactive effects:	A, B, C, E, F
Technology cost:	$ 5 incremental
Other costs:	$ none
Commercialization date:	1995
Measure life:	6 years
Technically feasible applications:	80%
Data quality:	C
Cost of saved energy:	$ 0.03/kWh
Savings potential:	0.5%
Current status:	FLDTEST
Next steps:	DEM
Notes:	Base=fluor. loads only; 29% new commercial stock; 3500 hrs./yr. usage
Sources - savings:	Atkinson et al. 1992
cost:	Atkinson et al. 1992
load shape:	PG&E 1992b
measure life:	n/a
other:	n/a
Principal contact:	Sam Berman, LBL, Berkeley, CA (510) 486-5388

L10. Advanced Reflector Design

Currently produced fluorescent luminaires range in efficiency (the ratio of light leaving the fixture to the amount of light produced by the lamps within the fixture) from 30-70%. Low luminaire efficiencies are particularly common in fixtures designed for low glare. However, improvements in the design of luminaires, and in particular reflectors, can increase fixture efficiencies with little or no compromises in glare control.

EPRI is currently sponsoring research by Centre d'Energetique in Paris on the use of nonimaging optics in luminaire design. The modification of reflector materials and geometry can improve light distribution and minimize trapping of radiation within the luminaire, increase fixture efficiency, and potentially lengthen lamp life due to cooler operation.

Energy savings from this technology are uncertain, but theoretically range from 15-25%. Costs for improved reflectors are not determined at this time. An estimate of $20 above standard reflector costs was used for this analysis, but this estimate is very uncertain. Other costs, such as the savings from fewer lamp and ballast replacements with the installation of fewer fixtures, are uncertain and were not included in the analysis.

The EPRI project will produce prototype luminaires as well as guidelines for improved reflector design by manufacturers by 1994 (EPRI, 1992). If the EPRI project yields positive results, utilities should consider offering incentives to fixture manufacturers to begin production of these materials through a Golden Carrot program. Demonstration projects and the incorporation of luminaires with advanced reflector designs into lighting rebate programs would also be useful.

L10. Advanced reflector design

Advanced reflectors improve fixture efficiency to near 90%

Market sectors:		C&I
End-use:		LIGHT
Market segment:		NEW
Typical unit size:		1 2 lamp T8/electronic ballast
Base case -		
Description: 70% efficient fixture		
Efficiency:		4060 lumens (output)
Energy use:		210 kWh/yr
New technology -		
Efficiency:		5075 lumens (output)
Energy use:		168 kWh/yr
Electricity savings:		42 kWh/year
Gas savings:		0 therms/year
Percent savings:		20%
Summer demand savings:		0.036 kW
Winter demand savings:		0.024 kW
Interactive effects:		A, B, C, E, F
Technology cost:	$	20 incremental
Other costs:	$	negative
Commercialization date:		1995
Measure life:		20 years
Technically feasible applications:		80%
Data quality:		C
Cost of saved energy:	$	0.04/kWh
Savings potential:		0.6%
Current status:		RES
Next steps:		GC
Notes:		Base=fluor. loads only; 29% new commercial stock

Sources - savings:	EPRI 1992
cost:	EPRI 1992
load shape:	PG&E 1992b
measure life:	EPRI 1992
other:	n/a
Principal contact:	Larry Ayers, EPRI Lighting Info. Office, Oakland, CA (800) 525-8555

L11. Thermal Bridging for Fluorescent Fixtures

Fluorescent lamp efficacy is greatly affected by the temperature of the lamp wall. The ideal minimum lamp wall temperature (MLWT) is approximately 104 degrees F (40 degrees C). Variations from this level compromise lamp performance. Lamp wall temperatures often rise to 130-140 degrees in enclosed fixtures, which can in turn reduce lumen output by 15-20%. The placement of heat conducting material against the lamp can lower the MLWT and thus improve lamp efficacy.

Lawrence Berkeley Laboratory (LBL) has developed two systems for standard four-foot lamp cooling. The first system consists of a liquid-filled pouch, attached to the top of the lamp and the shell of the luminaire, which convects heat from the lamp to the fixture shell and subsequently to the ambient air. The second system has a piece of metal snapped to the top of the lamp which conducts heat from the lamp to a cooling fin above the fixtures and then ambient air. Both systems require a small area of lamp contact, i.e. less than one square inch, and both can maintain MLWT at or near the desired level over a wide range of ambient temperatures (Competitek, 1992). LBL has preliminary agreements with three large luminaire manufacturers to produce prototypes of both systems (Siminovitch, 1992).

LBL has also developed a system for compact fluorescent lamp (CFL) cooling. A wire in the shape of a '7' has the short end attached to the lamp shoulder with the long end attached to a heat sink outside the fixture. LBL has recently granted a license to Lumatech to produce the units (Siminovitch, 1992). Lumatech will market them as an option to their current 9 and 13W CFL floodlights, and anticipate them being available in 1993 (Pelton, 1992).

LBL tests reveal that the CFL system can increase lumen output by 15-20% (Competitek, 1992). The production costs of the CFL system is less than $1; however, Lumatech stated that the devices will add $3-5 to the base price of their floodlights (Pelton, 1992). Production cost estimates for the 4' lamp systems range from $0.50-$3 (Competitek, 1992). For the purposes of this analysis, savings of 15% and a cost of $5 per fixture were assumed. Other savings are theoretically possible from fewer lamp replacements as a result of extended lamp life, but are uncertain and therefore not included in the analysis.

LBL anticipates that these systems will be applied primarily to new fixtures and installations, with a small retrofit market potential because of the high labor costs associated with retrofitting (Siminovitch, 1992). Given that product cost is so low in comparison to a fixture's total material and installation cost, market acceptance should not be a problem. However, architects and engineers must be made aware of the product and its advantages to ensure appropriate specification.

L11. Thermal bridging for fluorescent fixtures

Device dissipates heat/improves lamp efficiency

Market sectors:		COM
End-use:		LIGHT
Market segment:		NEW
Typical unit size:		1 2 lamp T8/electronic ballast
Base case -		
Description: no heat dissipation device in fixture, fixture efficiency 70%		
Efficiency:		4060 lumens (output)
Energy use:		210 kWh/yr
New technology -		
Efficiency:		4669 lumens (output)
Energy use:		179 kWh/yr
Electricity savings:		32 kWh/year
Gas savings:		0 therms/year
Percent savings:		15%
Summer demand savings:		0.027 kW
Winter demand savings:		0.018 kW
Interactive effects:		A, B, C, E, F
Technology cost:	$	5 incremental
Other costs:	$	negative
Commercialization date:		1993
Measure life:		20 years
Technically feasible applications:		100%
Data quality:		A
Cost of saved energy:	$	0.01/kWh
Savings potential:		0.4%
Current status:		PROTO
Next steps:		DEM, ED
Notes:		Operating 3500 hrs./yr.;29% new commercial stock

Sources - savings:	Siminovitch 1992; Pelton 1992
cost:	Competitek 1992
load shape:	PG&E 1992b
measure life:	Siminovitch 1992
other:	n/a
Principal contact:	Michael Siminovitch, LBL, Berkeley, CA (510) 486-5863

L12. Lower cost dimmable ballasts

Lower cost dimmable ballasts make dimming systems more affordable.

Market sectors:		COM
End-use:		LIGHT
Market segment:		ROB, NEW
Typical unit size:		10 2 lamp 4' fixtures
Base case -		
Description: 2 lamp T8/electronic ballast fixture		
Efficiency:		600 watts
Energy use:		2100 kWh/yr
New technology -		
Efficiency:		420 watts
Energy use:		1470 kWh/yr
Electricity savings:		630 kWh/year
Gas savings:		0 therms/year
Percent savings:		30%
Summer demand savings:		0.000 kW
Winter demand savings:		0 kW
Interactive effects:		A, F
Technology cost:	$	150 incremental
Other costs:	$	0
Commercialization date:		1995
Measure life:		20 years
Technically feasible applications:		30%
Data quality:		B
Cost of saved energy:	$	0.02/kWh
Savings potential:		0.7%
Current status:		RES
Next steps:		REB, DEM

Notes: Based upon fluor. loads; 3500 hrs./yr. oper.; cost incl. ballast and controls

Sources - savings:	Benya 1992
cost:	Benya 1992, Houghton 1993
load shape:	n/a
measure life:	Benya 1992
other:	n/a
Principal contact:	none

L12. Lower Cost Dimmable Ballasts

Daylight dimming and lumen maintenance systems have been commercially available for several years but have not made significant market penetration because of the high cost of dimmable fluorescent ballasts. Reduced ballast costs and improved dimming system components will allow wider use of such systems.

Dimmable ballasts operate where light levels are controlled through dimming in response to available daylight in a space. A photoelectric sensor relays a signal to the ballast, which in turn adjusts fluorescent lighting levels to maintain a relatively consistent light level in the space.

There have been problems with reliability and power quality with some manufacturers' dimmable ballasts, but manufacturers state that their products are continually improving (E-Source, 1992). Energy savings potential for these systems are difficult to quantify, but range from 25-35% of daytime lighting consumption where daylighting is available (Benya, 1992). As production levels increase, the cost of dimmable ballasts is expected to decrease by about 50%, resulting in a cost premium over non-dimming electronic ballasts of approximately 25% by 1995 (Houghton, 1993). For the purposes of this analysis, a $5 incremental cost per ballast plus $100 for the ballast controller were included.

Utilities could increase the utilization of this technology through increased rebate levels for dimmable ballasts, and by sponsoring demonstration projects.

L13. Integrated Fixtures and Controls

There are complex interactions between lighting fixtures, controls, and building HVAC systems. Ideally all lighting, controls, and HVAC components should be designed to complement each other; in reality, individual components are often designed by different individuals in new construction, and/or are altered in retrofits such that optimal system performance is not achieved.

The Electric Power Research Institute (EPRI) is currently sponsoring a project for design and test installations of integrated lighting fixtures and controls. Their contractor, Genlyte (Union City, NJ) has begun work on the project; however, detailed information on the project is considered proprietary. The integrated system would incorporate efficient lamps and ballasts, specular reflectors, high performance lenses, and fixture cooling devices in the luminaire with integrated occupancy and daylight controls. These would in turn be integrated with building energy management systems and controls (Ayers, 1992). Thus, optimal lighting and HVAC system performance is enhanced through the integration of system components.

Energy savings and cost estimates for the technology are not being disclosed by EPRI at this time. ACEEE estimated energy savings from integrated fixtures would range from 10% (as compared to buildings with T8 lamp/electronic ballasts and stand-alone occupancy/daylight controls) to 30% (as compared to buildings with T8/electronic ballasts and manual controls). Based upon current technology costs and preliminary system descriptions, ACEEE anticipates a $50 increased cost for the system as compared to a T8 lamp/electronic ballast system with manual controls, and a slight decrease in costs compared to T8 lamp/electronic ballast fixture with independent daylight/occupancy controls. Design, procurement, and installation costs would also be lower (compared to either base case) as a result of the simplicity of the system compared to individual components. For the purposes of this analysis, a $25 additional cost and 25% savings were used (assuming most buildings will not have daylight/occupancy controls already in place). These costs are highly uncertain.

The EPRI project includes integrated fixture development for new construction and major renovation applications, hardware testing and design guidance, and field demonstrations. PG&E will participate in the demonstration phase (EPRI, 1992). If the technology is fully developed and commercialized, utilities should promote its use through incorporation into lighting rebate programs and education of design professionals.

L13. Integrated fixtures/controls

Fixture & light/HVAC controls combined

Market sectors:		COM
End-use:		LIGHT
Market segment:		NEW
Typical unit size:		60 W
Base case -		
Description:		2 lamp T8/electronic ballast fixture
Efficiency:		60 watts
Energy use:		210 kWh/yr
New technology -		
Efficiency:		45 watts
Energy use:		158 kWh/yr
Electricity savings:		53 kWh/year
Gas savings:		0 therms/year
Percent savings:		25%
Summer demand savings:		0.000 kW
Winter demand savings:		0 kW
Interactive effects:		A, E, F
Technology cost:	$	25 incremental
Other costs:	$	0
Commercialization date:		1994-1995
Measure life:		20 years
Technically feasible applications:		40%
Data quality:		C
Cost of saved energy:	$	0.04/kWh
Savings potential:		0.3%
Current status:		RES
Next steps:		DEM, R&D
Notes:		Operating 3500 hrs./yr.; 29% new commercial stock

Sources - savings:	ACEEE
cost:	ACEEE
load shape:	n/a
measure life:	n/a
other:	Ayers 1992
Principal contact:	Larry Ayers, EPRI Lighting Info. Office, Oakland, CA (800) 525-8555

L14. Architectural Daylighting Devices

New architectural daylighting devices are currently in development and demonstration by various manufacturers. These devices work to passively or actively collect sunlight and transport it into a building to displace artificial light sources.

Light pipes transmit light through a pipe with a series of prisms or reflectors to inner spaces within a building. Prismatic light guides are hollow structures wherein light is transmitted by internal reflections and distributed along the surface of the guide. This type of system is effective for up to 75 feet of transmission. Reflective mirror guides work with a series of specular reflectors on inner wall surfaces to transport light and can be designed to distribute light through diffuse reflection. This design is flexible in its construction, but requires high, maintainable levels of reflectance in the specular materials. Lens guide designs operate with a series of lenses transmitting light from one lens to another further inside the space. All these systems can vary greatly in cost and efficiency, with higher cost systems yielding higher efficiencies. All these transmission/distribution systems have been utilized in high-end renovation and new construction with positive results.

Holographic glazings work by redirecting incident light towards the ceiling in the interior of the space from which the light is diffused. These glazings have an extremely thin, transparent, holographic pattern fabricated on the glass, which work based upon a design range of input and output angles. The technology is currently in development by a California-based firm, Advanced Environmental Research Group. Other daylighting devices, such as fiber optic light transmission and directional tracking skylights, are unlikely to be cost-effective due to high equipment and installation costs (see L24, L25, and L26 descriptions in Chapter 3).

Costs for light pipe systems are approximately $\$1/ft^2$ of lit area, but vary with building and lighting system design. Holographic glazing fabrication costs are estimated by LBL to be approximately $\$5/ft^2$ when commercialized. As stated above, energy savings vary greatly depending upon sophistication of the collection, transmission, and distribution equipment, but can range from 20-30% of lighting load (LBL, 1992). Other costs vary; lower hours of use would result in fewer lamp replacements, but more frequent switching could shorten lamp life. For the purposes of this analysis, other costs were not quantified.

Utilization of architectural daylight systems can be expected only in new construction and renovation projects. Light pipes and holographic glazings can be cost-effective in appropriate applications; small-scale demonstration projects and/or utility incentives should be put in place to promote their consideration in design.

L14. Architectural daylighting devices

Light pipes, holographic glazings, and fiber optics

Market sectors:	COM
End-use:	LIGHT
Market segment:	NEW
Typical unit size:	100,000 W (load for entire building)
Base case -	
Description:	66,000 s.f. bldg. w/ T8 lamps & elec. ballasts
Efficiency:	100000 watts
Energy use:	350000 kWh/yr
New technology -	
Efficiency:	72500 watts
Energy use:	253750 kWh/yr
Electricity savings:	96250 kWh/year
Gas savings:	0 therms/year
Percent savings:	28%
Summer demand savings:	0.000 kW
Winter demand savings:	0 kW
Interactive effects:	A, D, F
Technology cost:	$ 50000 incremental
Other costs:	$ varies
Commercialization date:	1995-2000
Measure life:	20 years
Technically feasible applications:	25%
Data quality:	B
Cost of saved energy:	$ 0.04/kWh
Savings potential:	0.3%
Current status:	RES
Next steps:	DEM
Notes:	base= 66,000 s.f.@ 1.5W/s.f.; 29% new commer. stock

Sources -	savings:	LBL 1992
	cost:	LBL 1992
	load shape:	n/a
	measure life:	n/a
	other:	n/a
Principal contact:		none

L15. Electrodeless HID

Both GE and Philips are currently working on electrodeless HID lighting systems. A high frequency ballast operates an electrodeless pressurized lamp, which contains a generator and coil to excite lamp gases.

The Philips 'Q' lamp system was demonstrated in Europe at the 1991 Hanover Fair and in the U.S. at the 1992 Lightfair; commercialization is still uncertain due to the high cost of the system but is not anticipated before 1995. Philips claims the system lasts up to 60,000 hours due to the elimination of the electrode, the most common component in HID lamp failure (Middlebrook, 1992).

The GE electrodeless HID system was also demonstrated in Europe in 1991. The lamp produces a white light with color rendition similar to metal halide. GE does not have conclusive data as yet on expected life, but it is expected to be similar to that of the Philips system (McGowan, 1992). As with the Philips system, GE is uncertain of the date of commercialization but does not anticipate release before 1995.

The GE high pressure discharge prototype is a 400 W system with approximately 60,000 lumen output, thus resulting in an efficacy of approximately 150 lumens per watt, above the 100-120 lumens per watt range of high pressure sodium lamps and roughly equivalent to the efficacy of low pressure sodium. Lamp costs are anticipated to be 20-30% higher than currently available standard HID lamps (McGowan, 1992). Assuming a typical high pressure sodium lamp cost of $35, the incremental cost of electrodeless lamp will be $10. A $25 lifecycle cost credit for one avoided lamp replacement over the system 15 year life is included in the analysis.

The technology is primarily targeted at new construction and renovation, and therefore requires investment by fixture manufacturers for marketable luminaire and control system packages. To date, the lamp manufacturers involved in R&D for this technology are not aware of any fixture manufacturers interested in developing such a system as the product is not yet proven. Utility support could help accelerate the commercialization of the lamps, which in turn could encourage fixture manufacturers to utilize the technology in their product designs.

L15. Electrodeless HID

High frequency ballast runs electrodeless lamp

Market sectors:	C&I
End-use:	LIGHT
Market segment:	NEW
Typical unit size:	60,000 lumens
Base case -	
Description:	500 watt high pressure sodium/magnetic ballast
Efficiency:	500 watts
Energy use:	1750 kWh/yr
New technology -	
Efficiency:	370 watts
Energy use:	1295 kWh/yr
Electricity savings:	130 kWh/year
Gas savings:	0 therms/year
Percent savings:	26%
Summer demand savings:	0.11 kW
Winter demand savings:	0.074 kW
Interactive effects:	A, B, C, F
Technology cost:	$ 10 incremental
Other costs:	$ -25 over lifecycle
Commercialization date:	1995-2000
Measure life:	15 years
Technically feasible applications:	90%
Data quality:	B
Cost of saved energy:	$ -0.01/kWh
Savings potential:	0.3%
Current status:	RES
Next steps:	R&D
Notes:	3500 hrs./yr. oper.; 29% new commer. s.f.; other costs for displaced HID lamp replacements
Sources - savings:	McGowan 1992
cost:	McGowan 1992
load shape:	PG&E 1992b
measure life:	McGowan 1992
other:	n/a
Principal contact:	Terry McGowan, GE, Cleveland, OH (216) 266-3234

S1. High R Windows

Aluminum frame windows with clear double glazing are now used in most new residential construction in California. These windows can have whole-window U-values of as high as 0.9 Btu/hr-sqft, depending on size and frame width. When new Title 24 window standards go into effect in July 1993, all windows will have to be certified to have a maximum U-value of at least 0.75, depending on climate zone. Builders will most likely meet this standard by using either thermally broken aluminum or vinyl frames. Changes to the glazing would not be required.

Recent improvements in frames, low emissivity (low-e) and spectrally selective glazings, inert gas fills, and spacers have resulted in windows with whole-window U-values of 0.3 and lower at reasonable cost. Vinyl frames with U-values of about 0.5 have been available for many years. New designs which eliminate steel reinforcing, use better designed cross sections, and have foam-filled exterior cavities can have U-values as low as 0.29 (Goldman, 1992). Another promising frame material is fiberglass (manufactured by Owens Corning). These frames are "pultruded" from high density fiberglass board and have whole-window U-values as low as 0.22 (Mumao, 1992). Low-e coatings, too, have been available for many years. In California, these coatings have been almost exclusively hard or pyrolytic coatings with emissivities of 0.2 and higher. The use of newer, soft-coat sputtered coatings, now used in the East and Midwest, can produce emissivities as low as 0.04 at no added cost (Larsen, 1992). Glazing units incorporating these coatings can also be made spectrally selective, creating a glazing unit with a shading coefficient of 0.5 while still maintaining 70% visible transmittance. These glazings have enormous potential in commercial buildings and residential buildings in cooling climates. As frames and glazing have improved, more research has focused on glass spacers, the remaining area of glazing heat transmission. There are presently various insulating spacers available, each with its own advantages and disadvantages. Since increasing numbers of glazing units are filled with inert gas, the key concern for spacers is the durability and longevity of the gas seal.

Conventional vinyl frames cost typically 20% less than otherwise-equivalent thermally broken aluminum frames. The addition of foam filling will add $.05 per lineal foot of frame to manufacturing costs. Fiberglass frames presently cost the same as wood frames but are expected to fall to that of vinyl (Hite, 1992). Low-e coatings add $1-2 to the cost of a clear glazing unit, irrespective of emissivity. Spacer costs vary greatly. With every manufacturer having its own type, the industry has not yet settled on a preferred technology. Cost premium is expected to be about 10%.

Rebates are presently being offered for many advanced glazing technologies. Education and demonstration projects would help design professionals understand how to specify and use these new technologies effectively.

S1. High R Glazing

Window consisting of vinyl frame, low-E coated argon filled glazing, and insulating spacer.

Market sectors:		R&C
End-use:		HC
Market segment:		NEW, RET
Typical unit size:		246 sqft glass
Base case -		
Description: Thermally-broken aluminum frame, clear double glass		
Efficiency:		0.63 U-value
Energy use:		300 + 1000 (therms + kWh)/yr
New technology -		
Efficiency:		0.3 U-value
Energy use:		249 + 797 (therms + kWh)/yr
Electricity savings:		203 kWh/year
Gas savings:		51 therms/year
Percent savings:		18%
Summer demand savings:		0.4 kW
Winter demand savings:		0.0 kW
Interactive effects:		B, D
Technology cost:	$	615 incremental
Other costs:	$	0
Commercialization date:		1993
Measure life:		30 years
Technically feasible applications:		100%
Data quality:		B
Cost of saved energy:	$	0.6/therm
Savings potential:		0.5%
Current status:		COMM
Next steps:		REB, DEM

Notes: Savings are a percentage of whole house heating and cooling energy.

Sources - savings:	Arasteh 1992
cost:	Larsen 1992, Goldman 1992, Hite 1992
load shape:	PG&E 1992a
measure life:	Arasteh 1992
other:	
Principal contact:	Windows & Daylighting Group, LBL, Berkeley, CA, (510) 486-6845

H1. High-Efficiency Packaged Air Conditioners

Over 50% of current commercial air-conditioning capacity is provided by self-contained "packaged units," with air handler, compressor, and condenser mounted in a metal box (Houghton et al., 1992). These units are typically roof-mounted to save interior space and have capacities ranging from 1 to 100 tons (5-20 tons are most common). Packaged units are attractive to builders and developers, especially those that build on speculation, because of their low first cost -- often less than $500 per ton. This emphasis, however, fosters inefficiency. For example, packaged units monitored by PG&E in San Ramon had an overall efficiency of 2.0 kW/ton (an EER of 6). California's Title 24 standards set a minimum efficiency of 8.9 EER at 95°F (1.34 kW/ton). Actual operating efficiencies can be even less, due to such factors as thin, uninsulated cases which can leak substantial amounts of hot rooftop air; constricted, high-velocity, high-pressure duct work; and undersized, low-performance heat exchangers.

Much higher efficiencies are obtainable at reasonable cost through better design, materials, and controls, but they have not been realized due to the emphasis on first cost. To address this problem, a collaboration of energy groups and utilities known as the Consortium for Energy Efficiency (CEE) is planning to implement a program similar to the Super Efficient Refrigerator Program ("Golden Carrot") for residential refrigerators. CEE's plan will offer a coordinated rebate designed to create a market for high-efficiency packaged equipment, eventually making efficient equipment the norm. Tentative efficiency goals of the program are a cooling EER of 12-12.5 at 95°F (1 kW/ton). Initial production is anticipated in 1995. Cost premiums are estimated at $200-300 per ton relative to an EER 8.9 unit (Nadel and Fitzpatrick, 1992).

Several manufacturers and groups are beginning to develop high-efficiency packaged units. EPRI is presently negotiating a cost share development program with a major HVAC manufacturer; the project will target EER's of 12 or more (Blatt, 1992). In another project, a group of researchers at Lawrence Berkeley Laboratory, with funding from the California Institute for Energy Efficiency, have been developing a prototype high-efficiency packaged air-conditioner. Their goals for the unit include a compressor-plus-condenser efficiency of .65 kW/ton and a supply fan efficiency 0.15 kW/ton at 95° ARI conditions. Targets for the prototype are a EER of 12.5 and an IPLV of 15 (Blumstein, 1993). They also expect to attain high part-load efficiency using a variable speed compressor and supply fan. LBL hopes to enlist a manufacturer to produce the units beginning in the near future. Estimated manufacturing cost premium is $300 per ton.

The CEE, EPRI, and LBL efforts should be supported but the availability of efficient units will not necessarily cause their specification and use. In speculative developments where the builder pays the first cost but not the energy bill, the lowest-cost unit may continue to be selected unless other incentives are provided, such as customer rebates or higher minimum performance standards.

H1. High Efficiency Packaged Air Conditioner

Commercial rooftop packed HVAC unit with 12 SEER / 4 COP

Market sectors:		COM
End-use:		COOL
Market segment:		NEW, ROB
Typical unit size:		10 ton
Base case -		
Description:		Title-24 rooftop package unit
Efficiency:		1.26 kW/ton
Energy use:		20000 kWh/yr
New technology -		
Efficiency:		0.8 kW/ton
Energy use:		12698 kWh/yr
Electricity savings:		7302 kWh/year
Gas savings:		0 therms/year
Percent savings:		37%
Summer demand savings:		4.0 kW
Winter demand savings:		0.0 kW
Interactive effects:		G
Technology cost:	$	3000 incremental
Other costs:	$	0
Commercialization date:		1995
Measure life:		12 years
Technically feasible applications:		50%
Data quality:		B
Cost of saved energy:	$	0.05/kWh
Savings potential:		1.1%
Current status:		RES
Next steps:		GC, REB
Notes:		Efficiencies are seasonal averages.

Sources - savings:	Greenberg 1992
cost:	Greenberg 1992
load shape:	PG&E 1992b
measure life:	Appliance 1991
other:	
Principal contact:	none

H2. Ground Source Heat Pump

Ground source heat pump (GSHP) technology originated with early heat pump installations in the 1950's. GSHP systems show great potential for energy conservation and demand reduction. However, significant market penetration has not occurred due to the high cost of ground heat exchangers. Recent developments in heat exchanger materials, configurations, installation methods, and anti-freeze solutions suggest costs can be significantly reduced.

GSHP's use the earth (rather than outdoor air) as the energy source/sink for heating and cooling. Using the relatively constant temperature of the earth has a number of advantages. In heating mode, GSHP's do not lose capacity at low outdoor temperatures, nor do they require supplemental electric resistance heat. At peak summer temperatures, GSHP's maintain high EER's and capacity; no defrost cycle is required, which saves energy and wear on the compressor and reversing valve.

Preferred GSHP configurations circulate an antifreeze solution through tubing buried in the ground and then through an antifreeze-to-refrigerant heat exchanger located in the heat pump. This configuration has almost no possibility of ground water contamination and uses 75% less refrigerant than a conventional split system. Steady state efficiencies of GSHP's can be as high as 4.5 COP heating and 16 EER cooling at standard conditions. GSHP's promise builder and marketing advantages, including elimination of the condensing unit space requirement and fan noise (Kavanaugh, 1992).

Until recently, ground heat exchangers were typically installed either in vertical bore holes or in extensive trenching systems. Costs for these methods have been as high as $1,200 per ton (Hunt, 1992). Researchers at Oklahoma State University have analyzed four low-cost, plastic pipe heat exchanger configurations. The two most promising are the "horizontal bore U-bend" and the "slinky coil." The "U-bend" is installed by a horizontal drilling machine that pulls a double length of pipe through a bored hole as the bit is extracted. The "slinky" is a coil of pipe that is translated sideways into a narrow trench. The horizontal U-bend had the highest performance per pipe foot, and the added benefit that its installation does not disturb the ground surface. The slinky coil had the highest performance per trench foot, and so would require the least land area (Bose, 1992). Estimated installed cost for the slinky coil is $700 per ton.

Another innovative installation technique used by PSI Energy in Indianapolis is the pre-installation of ground loops in an entire housing subdivision. This strategy resulted in an installed cost of $450 per ton for the ground loops and additional cost savings due to volume purchase of the heat pumps.

Levelized cost was based on the replacement of a 3 ton air-source heat pump at cost premium of $500 per ton. Savings potential was based on replacing systems in the 10% of California housing stock that is electrically heated. Savings may be greater in other regions of the country which have a higher proportion of electric heat and/or more extensive heating requirements.

Presently, the major barrier to GSHP use in California is the lack of a ground loop installation infrastructure. Demonstration projects using the slinky and U-bend coils would help to show the feasibility of these technologies. Utility programs similar to the packaging role played by PSI Energy may also be required to generate favorable GSHP economics (Anderson, 1993).

H2. Ground Source Heat Pump

Water source heat pump which uses the ground as an energy source/sink

Market sectors:		RES
End-use:		HC,WH
Market segment:		NEW
Typical unit size:		3 ton
Base case -		
Description: Air-source heat pump		
Efficiency:		2.2/9 COP/EER
Energy use:		4400 kWh/yr
New technology -		
Efficiency:		4/15 COP/EER
Energy use:		2470 kWh/yr
Electricity savings:		1930 kWh/year
Gas savings:		0 therms/year
Percent savings:		44%
Summer demand savings:		0.8 kW
Winter demand savings:		3.4 kW
Interactive effects:		none
Technology cost:	$	1500 incremental
Other costs:	$	0
Commercialization date:		1993
Measure life:		15 years
Technically feasible applications:		10%
Data quality:		B
Cost of saved energy:	$	0.07/kWh
Savings potential:		0.5%
Current status:		COMM
Next steps:		DEM, REB
Notes:	No fuel switch	

Sources - savings:	Anderson 1992
cost:	Hunt 1992
load shape:	PG&E 1992a
measure life:	Appliance 1991
other:	
Principal contact:	none

H3. Cool Ceiling with Displacement Ventilation

Commercial buildings are typically designed to provide continuous air flow and to bring in a substantial amount of outside ventilation air. In large buildings with central air handling systems, blowers and fans often consume 50% of cooling energy. To control duct sizes and costs, these large central air handling systems often operate against large static pressures and discharge air at relatively high velocities, mixing indoor air and circulating air contaminants.

The displacement ventilation/cool ceiling concept delivers sensible cooling from the ceiling using static cooling surfaces cooled by chilled water. Occupants are cooled by radiating body surface heat to the cool ceiling. This radiative surface heat exchange can reduce forced air delivery requirements by at least 50%. The ceiling surface temperature is maintained above the dew point to prevent condensation on the ceiling. The cool ceiling typically delivers 60 to 65% of total cooling, with the remainder delivered by forced cool air configured for "displacement ventilation" (Stahl and Keller, 1992).

In displacement ventilation 100% outside air, cooled by a central system, is supplied at low velocity near the floor and removed at ceiling level. The smaller forced air system removes moisture at the central coil and delivers dehumidified ventilation air. Because it is supplied at low velocity, the cool supply air "ponds" on the floor, slowly rising upward as it warms and as more arriving cool air pushes it upward. The air tends to rise around warm surfaces (chiefly people and equipment) without mixing horizontally. This upward "laminar flow" tendency allows warmer contaminated air (from people, smoke, etc.) to rise directly upward to the ceiling, where it enters air grilles for discharge outdoors, without recirculation. Overall cooling energy savings of up to 50% have been claimed compared to a current variable-air volume (VAV) system, based on European experience (Stahl and Keller, 1992).

Comfort data show that ceiling temperatures in the 64-68°F range increase comfort compared to conventional forced air cooling delivery, underscoring the rule that "cool head and warm feet are comfortable" (Fanger, 1988). In this temperature range, the cool ceiling can typically deliver 22 to 25 Btu/hr-ft^2. German cool ceiling component manufacturers may soon standardize cool ceiling capacity guidelines (Stahl and Keller, 1992).

Cool ceilings with displacement ventilation have been successfully applied in Europe and are now receiving more attention in North America. The technology appears particularly applicable to multi-story buildings in which under-floor plenums may be used for forced air supply. For one-story buildings, the cost of under-floor supply may deter use. Radiant ceiling cooling panels are available from several U.S. manufacturers, and have been frequently applied in hospital applications to minimize air mixing from room to room. Costs of hydronic ceiling panels are currently high, due in part to low volume (Wilkins and Kosonen, 1992).

Additional research efforts and monitored demonstration projects might help reduce panel costs, assess comparative energy performance, and identify optimal overall system configurations for common commercial building applications.

H3. Cool Ceiling with Displacement Ventilation

Low velocity floor-level delivery ventilation system with radiant cooling

Market sectors:		COM
End-use:		HC,VENT
Market segment:		NEW
Typical unit size:		50,000 sqft office
Base case -		
Description: VAV		
Efficiency:		3.5 kWh/sqft-yr
Energy use:		175000 kWh/yr
New technology -		
Efficiency:		2.3 kWh/sqft-yr
Energy use:		115000 kWh/yr
Electricity savings:		60000 kWh/year
Gas savings:		0 therms/year
Percent savings:		34%
Summer demand savings:		13.2 kW
Winter demand savings:		0.0 kW
Interactive effects:		C
Technology cost:	$	100000 incremental
Other costs:	$	0
Commercialization date:		1993
Measure life:		25 years
Technically feasible applications:		100%
Data quality:		B
Cost of saved energy:	$	0.12/kWh
Savings potential:		0.3%
Current status:		COMM
Next steps:		DEM, ED
Notes:	Ventilation savings only	

Sources - savings:	Stahl 1992
cost:	DEG
load shape:	PG&E 1992b
measure life:	
other:	
Principal contact:	none

H4. Cool Storage Roof

Many non-residential buildings have large, flat (or low-slope) roof surfaces with an unobstructed view of the sky. These roofs typically become much warmer than outdoor air in daylight hours and cooler than outdoor air at night (they cool by radiation to the cold night sky). Thermal characteristics of conventional roofs contribute to space cooling loads and fail to take advantage of cool night conditions.

Davis Energy Group has developed a cool storage roof (CSR) system for use in commercial buildings. The roof consists of a 3.5" water "ballast" layer atop a single-ply roof membrane; the ballast water supports 3"-thick, floating, rigid foam insulation panels. At night in summer, the ballast water is sprayed over the insulation panels and cooled by sky radiation and evaporation. The cooled water (and rainfall) drain through interlocking panel joints. Collected rainfall overflows through clog-proof, below-panel drains. The roof membrane is completely isolated from outdoor conditions and should outlast conventional roof systems. Cooling is delivered either directly through the roof deck to occupied space below, or by pumping the night-cooled water to heat-exchange coils. The system is best suited to low-rise buildings in dry California climates, as system performance would degrade at high humidity levels. The system also offers fire-protection advantages in addition to energy-saving and protected-roof benefits.

The CSR system was developed under the California Energy Commission's Energy Technologies Advancement Program (ETAP), and is estimated to have 50-90% cooling-energy savings on typical non-residential buildings based on computer simulations. The large CSR water volume may be used as a thermal-energy storage reservoir for auxiliary cooling, further reducing cooling capacity requirements. Incremental installed costs for the roof components are estimated to be $2.50 per square foot, but HVAC system installed cost savings will often exceed this value. Based on full-year hourly simulations and current energy rates, annual energy cost savings will range from $0.15/sqft-yr. in lightly loaded coastal buildings to $0.75/sqft-yr. for high-load, inland valley buildings. Projected paybacks are zero to three years for most new construction (Davis Energy Group, 1992a). Paybacks are faster on new construction projects because savings from reduced cooling capacity requirements largely pay the incremental system cost. For retrofit projects, projected paybacks are six to ten years.

A 6500 sqft retrofit demonstration system has been operating on a state building in Sacramento since August, 1991. The patented system is being commercialized under the "WhiteCap" trade name by Roof Science Corporation, Davis, CA. The system may also be used as a cooling tower substitute, winter solar heating storage reservoir, and horizontal distribution system in water-loop heat pump systems.

Convincing architects, builders, and owners of superior roof performance despite the large contained water volume is a major CSR marketing hurdle. Additional demonstration projects are recommended as the next developmental step.

H4. Cool Storage Roof

Water stored on a flat roof under foam insulation is cooled by nighttime spray

Market sectors:		COM
End-use:		COOL
Market segment:		NEW, RET
Typical unit size:		50,000 sqft
Base case -		
Description: Rooftop package units		
Efficiency:		3.39 kWh/sqft-yr
Energy use:		169500 kWh/yr
New technology -		
Efficiency:		1.44 kWh/sqft-yr
Energy use:		72000 kWh/yr
Electricity savings:		97500 kWh/year
Gas savings:		0 therms/year
Percent savings:		58%
Summer demand savings:		134 kW
Winter demand savings:		0.0 kW
Interactive effects:		B,C
Technology cost:	$	17500 incremental
Other costs:	$	0
Commercialization date:		1993
Measure life:		30 years
Technically feasible applications:		50%
Data quality:		C
Cost of saved energy:	$	0.01/kWh
Savings potential:		1.7%
Current status:		FLDTEST
Next steps:		DEM, REB
Notes:		Savings based on two story office in Fresno

Sources - savings:	DEG 1992a
cost:	DEG 1992a
load shape:	PG&E 1992b
measure life:	DEG 1992a
other:	
Principal contact:	Thomas Mackean, Roof Science Corporation, Davis, CA, (916)757-4844

H5. GAX Absorption Heat Pump

Absorption heating/cooling systems use chemical absorption instead of compression and expansion (as in compressor-driven systems) to evaporate refrigerant. A sorbent solution absorbs the refrigerant as it evaporates from the evaporator. Refrigerant is driven out of solution from the sorbent by circulating the "weak" sorbent through a generator, where heat is applied and refrigerant is boiled off. Refrigerant vapor from the generator is condensed and cycled back to the evaporator. Heat is extracted from the absorber (heat of dilution), and from the condenser. In double-effect absorption cycles, heat derived from refrigerant vapor boiled from solution in the first-stage generator is used to boil out additional refrigerant in the second stage generator.

When used for cooling, heat is transferred from indoor air to the evaporator using heat exchangers. In the heating cycle, heat of evaporation is obtained from outdoor air, and heat from the condenser and absorber are applied to heating loads. This heat can be used to satisfy domestic hot water as well as space conditioning loads.

Both ammonia/water and lithium bromide/water refrigerant pairs have been used in commercialized equipment. In the former, ammonia is the refrigerant; in the latter, water. Natural gas is typically used to heat the generator, though steam and hot water fired systems are also produced for high-tonnage commercial applications.

Residential gas-fired absorption air conditioners were promoted by California gas utilities in the late 60's and early 70's, but the market faded due to poor reliability. Current uses of the technology are primarily large central system chillers (see H21) and refrigerators for recreational vehicles, though residential equipment is still available. Servel, a long-time U.S. producer of absorption equipment, produces residential and commercial cooling equipment with COP's of 0.48.

Phillips Engineering Company is introducing a unit using a generator-absorber heat exchange (GAX) cycle for residential and small commercial heating/cooling applications with cooling and heating COP's presently at 0.8 and 1.7, respectively. COP's of 0.9 and 1.8 are targeted for commercialization. The system employs ammonia/water refrigerant pairs and uses a "recuperative" cycle that transfers nearly all of the heat from the absorber into the generator. Other purported advantages include high heating efficiency at low outdoor temperature (1.4 COP at 0°F), low equipment cost, 20-year life, and low maintenance. Units are being lab tested this year. Field tests are scheduled for 1994, and commercialization by 1996 (Phillips 1993).

Although the unit has the potential to substantially reduce cooling costs and peak power requirements, its source energy efficiency is only equal to that of a 10 SEER air conditioner. Its heating efficiency however is over twice that of a 78% AFUE furnace (not counting outdoor fan energy). Cost premium is expected be 60% of the premium of a high-efficiency furnace/air conditioning system (95% AFUE, 13 SEER). This was estimated at $900 for our economic analysis. Presumed maintenance advantages were not included.

Utility involvement in R&D and field testing is recommended as this technology has the potential both to reduce source energy use and eliminate peak residential air conditioning electric load.

H5. GAX Absorption Heat Pump

Gas fired recuperative generator-absorber cycle heat pump.

Market sectors:		RES
End-use:		HC
Market segment:		NEW
Typical unit size:		3 ton
Base case -		
Description: Furnace/Air conditioner		
Efficiency:		0.78/10 AFUE/SEER
Energy use:		300 + 1000 (therms + kWh)/yr
New technology -		
Efficiency:		1.8/0.9 GAS SCOP
Energy use:		241 therms/yr
Electricity savings:		600 kWh/year
Gas savings:		59 therms/year
Percent savings:		30%
Summer demand savings:		2.0 kW
Winter demand savings:		0.0 kW
Interactive effects:		none
Technology cost:	$	900 incremental
Other costs:	$	-24 /year
Commercialization date:		1996
Measure life:		20 years
Technically feasible applications:		100%
Data quality:		C
Cost of saved energy:	$	0.08/kWh
Savings potential:		1.1%
Current status:		PROTO
Next steps:		R&D, DEM
Notes:	Other cost is gas savings at $0.4/therm	

Sources - savings:	Philips 1992
cost:	Philips 1992
load shape:	PG&E 1992a
measure life:	Phillips 1992
other:	
Principal contact:	B.A. Phillips, Phillips Engineering Company, St. Joseph, MI, (616) 983-3935

H6. Indirect/Direct Evaporative Cooling

Evaporative coolers have been widely used for years in residences of the southwestern United States, but with the advent of compressor-driven air conditioning, they have become regarded as a low-quality cooling technology. These direct evaporative coolers (often called "swamp coolers") reduce the temperature of outdoor air by adding moisture. They supply large quantities of cooled and humidified outdoor air, and require discharge (typically through open windows) of equivalent indoor air quantities. In hot weather, direct evaporative supply air is sometimes too humid to fall within industry standard comfort limits.

Indirect/direct evaporative cooling (IDEC) systems improve on simple direct systems by precooling outdoor air without adding moisture before the direct stage using an evaporative heat exchanger. Various types of indirect evaporative heat exchangers may be used, including tubes or parallel plates fed by evaporatively cooled air and cooling coils supplied with evaporatively cooled water. Experimental work by Professor Hofu Wu of Cal Poly Pomona, and simulation work by Joe Huang at Lawrence Berkeley Laboratory (among others), indicate that IDEC systems have the potential to satisfy full residential cooling loads in most California climates while maintaining indoor air within accepted humidity limits (Huang and Wu, 1992).

IDEC cooling capacities and efficiencies are much more sensitive to outdoor wet bulb temperature than to dry bulb; at a fixed wet bulb temperature, cooling capacity actually increases slightly as dry bulb temperature increases. IDEC systems are rated in effectiveness, defined as the percentage of the wet bulb depression to which supply air is cooled; a 100% effective IDEC system delivers supply air at the wet bulb temperature. Typical units have effectiveness ranges from about 95% to 130% (the higher the better). IDEC systems can significantly reduce cooling loads, particularly if house discharge air is exhausted through the attic rather than windows (which cools the attic). Cooling load reduction accrues from eliminating latent loads; reducing ceiling, infiltration, and duct heat gains; and increasing air flow rates.

Single package residential IDEC systems are not currently available. Adobe Air of Phoenix markets a modular IDEC system in their MasterCool line, consisting of an advanced "rigid media" direct stage with one or two indirect evaporative precooling sections. Each indirect section has its own fan that moves evaporatively cooled "secondary air" between parallel plates. Outdoor air pulled through alternate plate passages by the supply blower is cooled (through the plates) by secondary air, which is then discharged. MasterCool units are large; a two-ton unit is 42" wide, 60" long, and 38" high. The units may be ground or roof mounted. SEER's of 20-35 are expected in California applications (AdobeAir, 1992).

Packaging, HVAC integration, and consumer acceptance are the major (and related) issues facing IDEC systems. Available units are large and are typically installed with duct systems separate from the heating system. An improved design which integrates with the conventional forced-air system is currently being developed by Davis Energy Group under the California Energy Commission's Energy Technologies Advancement Program (ETAP). The project began in early 1992 and is scheduled for completion in early 1994. Beutler Heating and Air Conditioning, California's largest residential contractor, is a partner in AMIDEC development and implementation. A monitored ten-unit field test and market studies are included in the project. Anticipated AMIDEC SEER's are in the 40+ range. Data presented here are based on the ETAP technology, for which the projected incremental installed cost is $175 for a 2.5-ton equivalent system.

Additional research and development, followed by demonstration projects, are the next steps in furthering this technology.

H6. Indirect/Direct Evaporative Cooling

Combination of indirect heat exchanger and direct evaporative cooling

Market sectors:		RES
End-use:		COOL
Market segment:		NEW, RET
Typical unit size:		3 ton
Base case -		
Description: 3 ton vapor compression		
Efficiency:		10 SEER
Energy use:		1000 kWh/yr
New technology -		
Efficiency:		25 SEER
Energy use:		400 kWh/yr
Electricity savings:		600 kWh/year
Gas savings:		0 therms/year
Percent savings:		60%
Summer demand savings:		1.2 kW
Winter demand savings:		0.0 kW
Interactive effects:		none
Technology cost:	$	175 incremental
Other costs:	$	20 /year
Commercialization date:		1993
Measure life:		15 years
Technically feasible applications:		90%
Data quality:		B
Cost of saved energy:	$	0.06/kWh
Savings potential:		1.0%
Current status:		PROTO, COMM
Next steps:		DEM, REB, ED
Notes:	$100 dollar pad replacement every 5 years	

Sources - savings:	Bourne 1992
cost:	Bourne 1992
load shape:	PG&E 1992a
measure life:	
other:	
Principal contact:	none

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H7. Adsorption Heat Pump

In "sorption cooling", refrigerant flow and associated heat transfers are achieved by absorbents (substances which change chemically, typically liquid) or adsorbents (which form mixtures, typically solid), eliminating the need for mechanical compressors. Cooling occurs when "sorbants," chemical "sponges" with the capacity to absorb 50-75% of their mass in "sorbate" (refrigerant), combine with the sorbate in the evaporator. Heat is given off when a heat source is used to separate the chemical components in a "generator."

Absorption cooling has been widely used in recreational vehicles (as the "gas refrigerator"), and in both industrial and domestic uses when electric power is limited or lower cost heat energy is available. High initial and maintenance costs have limited general adoption of the technology (see H6). However, recent advances in solid complex-compound adsorbent chemistry may improve the competitive position of adsorption chillers and heat-pumps vs. vapor-compression technology. Adsorption is the result of chemical bonds formed between sorbant and sorbate, which create a partial vacuum within the sorbant. Heat reverses the process by raising the internal vapor pressure above that of the surroundings, causing sorbate to be driven off.

In a solid adsorbent cooler, two sorbant beds are utilized: one initially saturated, the other depleted. The saturated bed is heated, driving refrigerant through a condenser, expansion valve, and evaporator, through which it is drawn by suction from the second bed. Heat of adsorption from the receiving bed is rejected, maintaining adsorption temperature. After five to fifteen minutes, depending on system design, the first bed is desorbed and the second saturated. Bed heating and cooling are reversed and valves adjust to maintain refrigerant flow; continuous cooling is provided by this periodic cycling.

Natural gas is typically used to drive desorption, which occurs above about 235°F. Adsorption occurs below 120°. The beds and valves substitute for all-mechanical compression, making the system simple, low-maintenance, and easily scalable. Current solid adsorbents (non-toxic, inorganic metal salts) have capacities of 0.75:1, by weight, of refrigerant to sorbant; requiring 15-20 pounds of sorbant per cooling ton. Power density of sorbants is typically 4000 Btu/lb. Over 100 media are available to fit a wide range of requirements.

Applications envisioned to date include residential heat pumps, commercial chillers, low-temperature (20° to -80°F) refrigeration, and existing or novel appliance uses. Efficiency estimates are significantly higher than for current absorption systems, with projected COP's of 1.7 heating and 1.1 cooling (Rockenfeller, 1992). Cost premium is estimated at $300 - $400 per installed ton vs. conventional cooling.

Rocky Research in Boulder City, NV is developing adsorption heat pump units. Prototype tests are underway and commercialization is anticipated in 1998 (Kirol, 1992) for a residential heat pump/chiller. Continuing research and development are recommended to advance system commercialization.

H7. Adsorption Heat Pump

Gas fired heat pump using two solid sorbent beds and a gaseous refrigerant.

Market sectors:		R&C
End-use:		HC,REF
Market segment:		NEW
Typical unit size:		3 ton
Base case -		
Description: Furnace/Air conditioner		
Efficiency:		0.78/10 AFUE/SEER
Energy use:		300 + 1000 (therms + kWh)/yr
New technology -		
Efficiency:		1.5/0.7 GAS SCOP
Energy use:		299 therms
Electricity savings:		600 kWh/year
Gas savings:		1 therms/year
Percent savings:		16%
Summer demand savings:		2.0 kW
Winter demand savings:		0.0 kW
Interactive effects:		none
Technology cost:	$	300 incremental
Other costs:	$	0
Commercialization date:		1998
Measure life:		20 years
Technically feasible applications:		100%
Data quality:		C
Cost of saved energy:	$	0.04/kWh
Savings potential:		0.7%
Current status:		PROTO
Next steps:		R&D
Notes:		Savings based on residential unit - refrigeration has large potential

Sources - savings:	Rockenfeller 1992
cost:	Rockenfeller 1992
load shape:	PG&E 1992a
measure life:	Rockenfeller 1992
other:	
Principal contact:	none

H8. Improved Ducts and Fittings

Recent monitoring work in Florida, California, and other states indicates that duct air leakage is greater than formerly assumed; this leakage causes substantial decreases in overall HVAC capacities and efficiencies. Flex duct, the predominant type of residential duct installed in California, has high pressure drop and is often sealed to plenum and register "boots" with duct tape. Duct tape does not create a permanent seal, contributing to diminished HVAC performance after the first several years of operation. 15% duct leakage reduces efficiency and capacity of an SEER 10 air conditioner by 50% when two-thirds of the leakage enters through attic returns on a warm summer day (Coyne, 1992).

Researchers at Lawrence Berkeley Laboratory are working on high-performance flex duct with higher thermal resistance and lower pressure drop than standard flex duct. They are also working cooperatively with plastics experts to develop leakproof duct fittings for new ductwork in residential applications. The new designs will create permanent, positive connections between ducts, registers, and plenums without tape or mastics. Improvements in the design of plastic-molded boots will facilitate positive seals, even when installed by low-skill personnel. The improved systems will not prevent catastrophic failures such as unconnected ducts and/or missing sections, but they should substantially eliminate the leakage that typically occurs at field-installed ductwork joints. Commercialization is expected within two to three years (Modera, 1992).

Potential savings are estimated at 70% of air leakage and 50% of conduction losses. 50% savings in total duct losses were assumed in cost-effectiveness calculations. System cost projections are preliminary; the cost of materials is expected to be higher than for conventional ductwork, but faster connections should reduce field labor. A net cost increase is likely and a 20% premium over conventional duct work was assumed for cost-effectiveness calculations.

Rebates or requirements as part of new construction programs, and mandated maximum duct leakage levels as part of building codes, would be valuable in accelerating implementation of improved duct and fitting systems.

H8. Improved Ducts and Fittings

Leak-proof, high performance replacements for standard flex duct.

Market sectors:		RES
End-use:		HC
Market segment:		NEW, RET
Typical unit size:		6 duct runs
Base case -		
Description: R-4.2 flex duct		
Efficiency:		30 % loss
Energy use:		300 + 1000 (therms + kWh)/yr
New technology -		
Efficiency:		10 % loss
Energy use:		240 + 800 (therms + kWh)/yr
Electricity savings:		200 kWh/year
Gas savings:		60 therms/year
Percent savings:		20%
Summer demand savings:		0.5 kW
Winter demand savings:		0.0 kW
Interactive effects:		B
Technology cost:	$	200 incremental
Other costs:	$	-12 /year
Commercialization date:		1995
Measure life:		25 years
Technically feasible applications:		100%
Data quality:		B
Cost of saved energy:	$	0.0/therm
Savings potential:		0.8%
Current status:		PROTO
Next steps:		DEM, REB

Notes: Assumes all new and 10% of old stock. Other cost is electric savings at $0.06/kWh.

Sources - savings:	Modera 1992
cost:	Modera 1992,Jacobson 1992
load shape:	Coyne 1992
measure life:	Modera 1992
other:	
Principal contact:	Mark Modera, LBL, Berkeley, CA, (510)486-4678

H9. <u>Internal Access Duct Sealants</u>

Duct sealing has been shown to be one of the most cost-effective residential energy retrofit measures due to the large losses found in both old and new ductwork. A recent study has shown that pre- and post-Title 24 homes have similar duct losses - often as high as 30% (Modera, 1992). Present remedies include leak detection using blower doors, pressure/flow sensors, and smoke sticks; and leak sealing using mesh tape and mastic. While these methods are very effective -- sealing up to 74% of the duct leakage (Coyne, 1991) -- they are also labor intensive and expensive, and can be impossible when ducts are inaccessible.

Internal access duct sealants are aerosol compounds that are sprayed inside existing ducts. They seal in much the same way an aerosol can "flat fixer" seals a punctured tire. In laboratory tests they have been shown to seal 3-4 mm holes up to 20 feet down a duct in 10 minutes. They are also extremely effective at sealing diffuse leaks such as those found in spiral ducts. When used to seal a residential system, the ducts must first be inspected; holes larger than 10 mm and disconnected fittings must be sealed by other means. Then filter paper is placed over the supply registers and the ducts are pressurized with a small fan before the aerosol is injected into the plenum.

Because access to the ductwork is not necessary, the time and cost of duct sealing can be significantly reduced with aerosol sealants, especially on houses with ductwork in hard-to-reach locations. While traditional methods can cost $200-$300 (Jacobson, 1992, Consol 1990), researchers at Lawrence Berkeley Laboratory estimate that aerosol sealing will cost approximately $100 per house and should be commercialized within one year (Modera, 1992).

Aerosol duct sealing should be easily incorporated into existing utility retrofit programs. In addition, monitored demonstration projects, educational materials, and rebates for duct sealing services would aid in achieving a large market penetration.

H9. Internal Access Duct Sealants

Aerosol spray seals ducts from the inside

Market sectors:		RES
End-use:		HC
Market segment:		RET
Typical unit size:		6 duct runs
Base case -		
Description: R-4.2 flex duct		
Efficiency:		30 % loss
Energy use:		300 + 1000 (therms + kWh)/yr
New technology -		
Efficiency:		15 % loss
Energy use:		255 + 850 (therms + kWh)/yr
Electricity savings:		150 kWh/year
Gas savings:		45 therms/year
Percent savings:		15%
Summer demand savings:		0.4 kW
Winter demand savings:		0.0 kW
Interactive effects:		B
Technology cost:	$	100 full
Other costs:	$	-9 /year
Commercialization date:		1993
Measure life:		15 years
Technically feasible applications:		75%
Data quality:		B
Cost of saved energy:	$	0.0/therm
Savings potential:		1.2%
Current status:		FLDTEST
Next steps:		DEM, REB

Notes: Other cost is electric savings at $0.06/kWh.

Sources -	savings:	Modera 1992
	cost:	Modera 1992
	load shape:	Coyne 1992
	measure life:	Modera 1992
	other:	
Principal	contact:	Mark Modera, LBL, Berkeley, CA, (510)486-4678

H10. Zeotropic Refrigerants

Because of their damaging effects on the ozone layer, CFC refrigerants will be phased out by January 1, 1996. Suppliers and equipment manufacturers are beginning conversion to non-CFC refrigerants. HCFC refrigerants, whose effect on ozone depletion is much less pronounced, will be phased out later. These impending phase-outs have spurred manufacturers to find stable, non-toxic replacements. Although energy efficiency is not the principal reason for this search, several new compounds have shown better performance than current refrigerants.

Refrigerants have historically been either single compounds or "azeotropic" mixtures which do not change composition or separate as they evaporate. As part of the Alternate Refrigerant Evaluation Program directed by the Air-Conditioning and Refrigeration Institute, zeotropic mixtures have been developed which have the potential to save energy compared to standard refrigerants. These mixtures, also known as "non-azeotropic refrigerant mixtures" (NARMs) and "blends," exhibit a change in saturation temperature during evaporation at constant pressure. When this effect is used in conjunction with a counterflow heat exchanger, there is a better match between the temperature gradients so that thermodynamic irreversibility is reduced, resulting in increased efficiency. Research at the University of Maryland on the substitution of a zeotropic mixture of R-22 and R-142b for R-12 in a residential refrigerator has shown efficiency improvements of up to 5% when used in combination with a counterflow heat exchanger and synthetic oil (He et al., 1992).

R-22 is an HCFC used in virtually all residential and small commercial air-conditioning compressors. Atochem NA has developed two R-22 replacement blends: R-32/R-134a and R-32/R-125, which have the potential for 15-20% efficiency improvement over R-22 (Lavelle, 1992). Use of zeotropic refrigerants in non-hermetic systems such as air-conditioners may complicate service work. Present R-22 charging methods would not be appropriate, as the concentration of a zeotropic mixture can change when there are leaks in a system. This potential problem must be addressed by new equipment designs and service training (Hughes, 1992).

Development of new refrigerants typically takes three to five years due to testing of lubricant compatibility and toxicity, and plant modification. Because zeotropic refrigerants will require new types of heat exchangers to attain maximum efficiency improvements, equipment manufacturers will require six to eight years to introduce compatible equipment. Therefore, commercialization of equipment using zeotropic refrigerants will not occur before 2000 (Lavelle, 1992). Costs for the new refrigerants are inherently higher for purification and extraction. The economic analyisis was based on an incremental cost of $15 per pound which is in the middle of the range of CFC replacement costs. Additional research and development are required to fully evaluate zeotropic refrigerants.

H10. Zeotropic Refrigerants

Zeotropic refrigerant mixtures with greater efficency due to varying condensing temp.

Market sectors:		R&C
End-use:		HC,REFFRZ
Market segment:		NEW, ROB
Typical unit size:		3 ton
Base case -		
Description: Vapor compression A/C		
Efficiency:		10 SEER
Energy use:		1000 kWh/yr
New technology -		
Efficiency:		11.8 SEER
Energy use:		850 kWh/yr
Electricity savings:		150 kWh/year
Gas savings:		0 therms/year
Percent savings:		15%
Summer demand savings:		0.3 kW
Winter demand savings:		0.0 kW
Interactive effects:		none
Technology cost:	$	90 incremental
Other costs:	$	0
Commercialization date:		2000
Measure life:		15 years
Technically feasible applications:		70%
Data quality:		C
Cost of saved energy:	$	0.06/kWh
Savings potential:		1.1%
Current status:		RES
Next steps:		R&D
Notes: 6 lbs of refrigerant @ $15/lb		

Sources - savings:	Lavelle 1992, He 1992
cost:	Lavelle 1992
load shape:	PG&E 1992a
measure life:	
other:	Hughes 1992
Principal contact:	Jim Lavelle, Atochem, Philadelphia, PA, (800) 852-5858

H11. Electrohydrodynamic Heat Transfer Enhancement

Heat exchange coils and surfaces are used in a variety of cooling and heating applications to transfer heat between fluids. Refrigerant-to-air coils are commonly used in residential air conditioning and heat pump systems; both refrigerant-to-water and water-to-air heat exchangers are used in many non-residential applications. Heat exchanger performance, size, and cost are significantly affected by fluid movement at the heat exchanger surface (more movement means better heat exchange). Techniques which enhance molecular movement promise improved heat exchange and reduced size and cost of the heat exchanger.

Electrohydrodynamic heat exchange enhancement (EHD) applies a high-voltage, low-current electric field to induce turbulence at the wall boundary layer, increasing the mixing and convective heat transfer of a contained refrigerant through the heat-exchanger wall. Experiments show increases in exchange efficiency ranging from 140% to 10,000%; the mean reported value is about 1500% (Ohadi, 1991). The effect appears at voltages above ~4kV/mm and increases approximately linearly with field strength. It is observed in dielectrics in both gas and liquid states, and is applicable to single-state or phase-change heat exchangers; water is not a suitable medium because its high conductivity requires significantly more power. EHD is most applicable in the case of laminar flows, but acts in concert with other exchange-efficiency enhancements such as grooved or finned walls. Of particular interest are effects on CFC substitutes, as these substances typically have low boundary-layer conductivity.

There appear to be few barriers to the commercialization of EHD; enhanced condensers and evaporators for refrigeration and space conditioning are under development in Japan and the United Kingdom. Toshiba and MITI are testing a prototype heat pump EHD condenser which shows a 600% increase in heat transfer with R114 (Ohadi, 1991). Implementation costs should be low -- the requirements are simple transformers and fine wire or mesh electrodes along refrigerant-line walls. Additional power consumption is only a few watts, and parasitic losses are minimal. There are no known adverse chemical effects. Safety of the technology is comparable to high voltages in televisions and electrostatic air cleaners.

The benefits of EHD are increased viability of CFC substitutes, reduced heat-exchange areas, and total power-consumption savings. Applications are seen in air-side enhancement of laminar and turbulent flows, furnaces, heat-recovery, air-cooled condensers and evaporators, and very low differential (1-3°F) heat exchangers. Cost and performance in actual HVAC equipment is difficult to predict at this time. Cost-effectiveness analyses assume a 15% efficiency increase at a $100 cost premium for a residential air conditioner but will be very dependent on the type of heat exchanger used.

Additional research and development, and subsequent demonstration projects should be encouraged.

H11. Electrohydrodynamic Heat Transfer Enhancement

High voltage field applied accross the heat exchanger increases effectiveness up to 10 times.

Market sectors:		R&C
End-use:		HC,REFFRZ
Market segment:		NEW, ROB
Typical unit size:		3 ton
Base case -		
Description: Vapor compression A/C		
Efficiency:		10 SEER
Energy use:		1000 kWh/yr
New technology -		
Efficiency:		11.8 SEER
Energy use:		850 kWh/yr
Electricity savings:		150 kWh/year
Gas savings:		0 therms/year
Percent savings:		15%
Summer demand savings:		0.3 kW
Winter demand savings:		0.0 kW
Interactive effects:		none
Technology cost:	$	100 incremental
Other costs:	$	0
Commercialization date:		1995
Measure life:		15 years
Technically feasible applications:		50%
Data quality:		C
Cost of saved energy:	$	0.06/kWh
Savings potential:		1.8%
Current status:		RES, PROTO
Next steps:		R&D, DEM
Notes:		

Sources -	savings:	Ohadi 1991
	cost:	Ohadi 1991
	load shape:	PG&E 1992a
	measure life:	
	other:	
Principal	contact:	none

W1. Pilotless Instantaneous Gas Water Heater

Although the national residential water heating market is approximately evenly divided between gas and electric water heaters, gas water heaters make up more than 90% of the stock in California (CEC, 1991) because Title 24 standards virtually prescribe gas. Almost all gas water heaters are of the conventional storage type: 30-60 gallon tank, 300-500 Btuh standing pilot, and 76-80% recovery efficiency. The market for low-cost, highly reliable gas storage water heaters is fully mature; the average lifetime for these units is 11-13 years (Rheem-Ruud, 1992). However, energy lost from the tank when the water heater is idle results in a "standby loss" of 30-50% of total water heater gas use, depending on hot water draw quantities (Davis Energy Group, 1991).

Instantaneous or "tankless" gas water heaters (IWH's) are widely used in Europe and Japan, where they are usually installed on bathroom and/or kitchen walls. In the United States, however, IWH's are perceived to have limited heating capacity and are used mostly in small homes and additions. Because they do not store hot water, but heat it as needed with a copper-tube heat exchanger, IWH's have the potential to eliminate standby losses associated with storage water heaters. However, IWH's currently on the market have standing pilots and therefore show only modest energy savings compared to tank-type heaters (with a tank-type heater, the pilot light helps keep water in the tank warm; with an IWH, heat given off by the pilot is wasted).

A pilotless (intermittent ignition) version of the Aquastar (a French IWH) has just been approved by the American Gas Association and is expected to be available in mid-1993. For a 67-gallon daily hot water draw, the pilotless Aquastar should reduce annual water heating costs by 32% compared to a storage gas water heater (Davis Energy Group, 1992b). Low voltage (24V) power is required for the intermittent ignition device. The most popular Aquastar unit (Model 125) has a input capacity of up to 125,000 Btu/hr and can heat almost four gallons per minute of continuous 115°F hot water flow from 65°F supply water (enough for a typical household's maximum hot water demand).

The pilotless Model 125 is expected to cost $350 more (installed) than a standard storage water heater (Muir, 1992). The Aquastar has an estimated life of up to 40 years but requires maintenance of the water valve approximately every three years. In France, where there is a large service infrastructure, this maintenance is provided under a contract purchased at the time of sale. Until IWH's are readily available, such service may be costly. A 25 year life is estimated with $60 maintenance every three years.

California Title 24 standards allow application of water heating credits to space conditioning loads, offering a substantial economic incentive for pilotless IWH installation. Utility support in the form of rebates and educational programs could accelerate market acceptance of this technology.

W1. Pilotless Instantaneous DHW

Instantaneous gas water heater with intermittent ignition

Market sectors:		RES
End-use:		WH
Market segment:		NEW, ROB
Typical unit size:		125,000 Btuh input
Base case -		
Description: Gas storage water heater		
Efficiency:		30 % standby loss
Energy use:		232 therms/yr
New technology -		
Efficiency:		0 % standby loss
Energy use:		162 therms/yr
Electricity savings:		0 kWh/year
Gas savings:		70 therms/year
Percent savings:		30%
Summer demand savings:		0.0 kW
Winter demand savings:		0.0 kW
Interactive effects:		none
Technology cost:	$	350 incremental
Other costs:	$	3 /year
Commercialization date:		1993
Measure life:		25 years
Technically feasible applications:		70%
Data quality:		B
Cost of saved energy:	$	0.4/therm
Savings potential:		1.8%
Current status:		PROTO, FLDTEST
Next steps:		REB, ED

Notes: Assumes same recovery efficiency, $20/yr maintenance, $150 conventional WH replaced at 12 years.

Sources - savings:	Muir 1992,DEG 1992b
cost:	Muir 1992,DEG 1992b
load shape:	
measure life:	Muir 1992
other:	
Principal contact:	Controlled Energy Corp., Waitesfield, VT, (800) 642-3111

W2. Combined Refrigerator/Water Heater

After space conditioning equipment, water heaters and refrigerators are the second and third largest energy users, respectively, in the typical American home. Individual refrigerators and water heating systems offer substantial energy conservation opportunities, but combining the two functions in a single appliance offers the potential of large energy savings, even without efficiency improvements. Typical 1993 refrigerator heat output could supply approximately half of typical household water heating needs; the remainder could be satisfied with a room air source to the refrigerator evaporator coil, to allow operation as an indoor heat pump water heater.

Southern California Edison funded a 1991 feasibility study by Davis Energy Group to evaluate the potential of the combined refrigerator/water heater (Davis Energy Group, 1991a). Project analyses indicated that (at current unit efficiencies) total refrigerator and water source heating energy use could be reduced by 45% (assuming 33% source efficiency) using indoor air source auxiliary water heating compared to conventional gas water heating. The unit has two main advantages over conventional individual appliances that would contribute to a reduction in source energy use:

- Hot water system heat losses would be reduced by eliminating the gas water heater and its center flue, and by locating the unit near the kitchen sink (whose many short hot water draws cause large piping losses).

- Refrigerator space conditioning impacts would be improved. A conventional air-cooled refrigerator acts as a resistance heater, decreasing heating loads and increasing cooling loads. The combined unit would be a space cooler (heating water rather than air), reducing cooling loads and allowing an efficient heating system to satisfy the increased heating loads.

The concept offers advantages to the builder through elimination of the water heater, platform, flue, gas line, and floor space requirements. The water-cooled condenser coil would not require dusting as do conventional refrigerators, but the air-source evaporator for auxiliary heat pump water heating would require a filter. Occasional de-scaling might be needed in areas with hard water.

The feasibility project involved the development and testing of a full-scale prototype using a new side-by-side refrigerator coupled with a custom storage tank. Prototype test results suggested design changes to deliver greater heat output to storage water. Appliance manufacturer participation is being solicited to develop a marketable product. The cost of the combined unit is expected to be $200 more than a conventional refrigerator and storage water heater. Retrofit applications may be limited by required kitchen piping revisions.

Additional research and development is required to fully demonstrate combined refrigerator water heater potential.

W2. Combined Refrigerator/Water Heater

Integrated appliance which uses waste heat from the refrigerator to heat water.

Market sectors:		RES
End-use:		WH
Market segment:		NEW
Typical unit size:		18 cf
Base case -		
Description: Gas storage water heater, 93 standards refrigerator		
Efficiency:		0.76 Recovery Eff.
Energy use:		223 + 744 (therms + kWh)/yr
New technology -		
Efficiency:		n/a
Energy use:		17 + 1451 (therms + kWh)/yr
Electricity savings:		-707 kWh/year
Gas savings:		206 therms/year
Percent savings:		57%
Summer demand savings:		0.1 kW
Winter demand savings:		0.0 kW
Interactive effects:		A
Technology cost:	$	200 incremental
Other costs:	$	42 /year
Commercialization date:		1998
Measure life:		12 years
Technically feasible applications:		80%
Data quality:		C
Cost of saved energy:	$	0.3/therm
Savings potential:		1.2%
Current status:		PROTO
Next steps:		R&D

Notes: Base case and new energy use includes space conditioning impacts. Other cost is additional electricity use at $0.06/kWh.

Sources -	savings:	DEG 1991a
	cost:	DEG 1991a
	load shape:	PG&E 1992a
	measure life:	Rheem-Ruud 1992
	other:	
Principal contact:		Dick Bourne, Davis Energy Group, Davis, CA, (916) 753-1100

W3. Ultrasonic Faucet Control

When manual lavatory faucets in both residential and nonresidential applications are turned on with nothing under the faucet, water is wasted. Wasted hot water has a direct energy impact, and wasted cold water has an indirect energy impact from water and waste treatment, and from pressurization (pumping).

SmartFaucet (TM) is a newly commercialized automatic faucet control intended for residential and commercial markets. SmartFaucet is offered as an economical alternative to infrared (IR) faucet controls currently on the market, the latter being priced at $300-900 installed.

SmartFaucet is designed to fit existing plumbing, taking the place of an aerator, and may be installed with a wrench and screwdriver in a few minutes. It is compatible with some low-flow aerators and restricting washers (an anti-theft version with integrated flow restrictor for public facilities is under development). About the size of a cigarette pack, the unit uses an ultrasonic sensor to activate water flow when an object moves within 4-12" below the outlet; flow stops immediately when motion ceases. SmartFaucet's downward sensitivity avoids the problem with horizontally-mounted IR sensors of inadvertently activating water flow from motion sensed in front of the sink. A nine-volt battery supplies power and lasts 9 to 12 months of daily use. Rechargeable batteries may be substituted. An LED indicates low battery condition and a manual switch provides override of the sensor if needed.

The manufacturer claims energy savings (undocumented) of 35-75% on kitchen faucets. Cost-effectiveness estimates are based on 40% savings at one kitchen faucet using 15% of total hot water for a residence (CEC, 1991). Purchase cost is $80 to utilities, $60 for volume purchases of 100,000 units or more, and $120 retail (Jones, 1992). The use of battery power adds a $2 per year maintenance cost. The measure may also apply to 10% of commercial hot water use (Bancroft et al., 1991). An added benefit in restaurants and medical offices is the sanitation protection provided by no-touch control.

Similar savings may be obtainable using much simpler and lower cost devices such as fingertip shut-off valves. Utility rebates and education programs should only be considered after field studies show measured savings data on this device.

W3. Ultrasonic Faucet Control

Battery powered device turns on water using ultrasonic sensor.

Market sectors:		R&C
End-use:		WH
Market segment:		NEW, RET
Typical unit size:		1 faucet
Base case -		
Description: Standard Aerator		
Efficiency:		n/a
Energy use:		232 therms/yr
New technology -		
Efficiency:		n/a
Energy use:		218 therms/yr
Electricity savings:		0 kWh/year
Gas savings:		14 therms/year
Percent savings:		6%
Summer demand savings:		0.0 kW
Winter demand savings:		0.0 kW
Interactive effects:		H
Technology cost:	$	80 full
Other costs:	$	2 /year
Commercialization date:		1993
Measure life:		10 years
Technically feasible applications:		80%
Data quality:		B
Cost of saved energy:	$	0.9/therm
Savings potential:		0.5%
Current status:		FLDTEST
Next steps:		REB
Notes:	$2/year for battery	

Sources - savings:	Jones 1992, CEC 1991
cost:	Jones 1992
load shape:	
measure life:	Jones 1992
other:	Competitek 1991
Principal contact:	Berry Jones, Conservation Corp. of America, Weston, MA, (617) 431-7707

R1. High-R Case Doors

Four percent of California electricity is used in supermarkets; about half of the energy used in food stores is for refrigeration. The energy efficiency challenge is to promote conservation while allowing access, or perceived access, to refrigerated products. Case doors and plastic curtain strips are in use, but they may discourage sales due to frost buildup or physical obstruction. Combating frost by use of heaters and blowers increases energy consumption.

Insulated, high-R case doors with fiberglass framing are in limited production by Zerowatt U.S.A. Corporation. The doors consist of multiple-glazed, low-e coated panes with fiberglass framing. The R-4 to R-5 insulation is sufficient to eliminate the need for anti-frost heaters on all but very low temperature (VLT) case doors. Additional savings may result from reducing the frequency of cabinet defrost cycles and tuning refrigeration equipment to the new conditions. If internal case lighting is added after retrofit to light produce, savings are reduced. Interactive effects with HVAC systems generate efficiency gains, as case refrigeration is a poor space-cooling method -- the energy saved in case cooling exceeds that lost by the space-cooling previously provided by the refrigerators.

Energy savings vary with case type. Typical savings are 40-50% for retrofitting open, low-temperature (LT) cabinets, 19-28% for open, medium-temperature (MT), 24% for LT heated-door retrofits, and little or no savings for high-temperature or tub-type cases (Shepard et al., 1990). Economics favor retrofitting high-R doors to new open LT or MT cases rather than purchasing new cases pre-fitted with the uninsulated doors currently available. Current cost is $280-300 per high-R door, and projected unit life is 15-20 years, based on durability tests exceeding 300,000 open-close cycles (Tennant, 1992).

The doors are suitable for about 75% of display-case energy uses (case doors are unsuitable for produce and meat because shoppers would leave them open too long), or about 55% of grocery refrigeration energy use.

A replacement test in 1992 at a California Safeway store on -10°F cases generated an annual savings projection of $93 per door over metal-framed conventional doors, based on three-weeks of monitoring. Another store chain has installed case doors on all its freezer cases and has observed no sales loss. They also observed a longer shelf life for dairy products in cases with the high-R doors (Tennant, 1992).

Case manufacturers should be encouraged through rebates or standards to include high-R doors on their new equipment. Demonstrations and rebates are recommended to encourage retrofit installations.

R1. High R Case Doors.

Fiberglass frames and low-e glass reduce or eliminate the need for door strip-heat.

Market sectors:		COM
End-use:		REF,FREEZ
Market segment:		RET
Typical unit size:		1 freezer door
Base case -		
Description: Metal frame doors with strip heat		
Efficiency:		n/a
Energy use:		5252 kWh/yr
New technology -		
Efficiency:		n/a
Energy use:		4160 kWh/yr
Electricity savings:		1092 kWh/year
Gas savings:		0 therms/year
Percent savings:		21%
Summer demand savings:		0.0 kW
Winter demand savings:		0.1 kW
Interactive effects:		A
Technology cost:	$	300 full
Other costs:	$	0
Commercialization date:		1993
Measure life:		15 years
Technically feasible applications:		75%
Data quality:		B
Cost of saved energy:	$	0.03/kWh
Savings potential:		0.5%
Current status:		COMM
Next steps:		REB, DEM

Notes: Estimates are for metal door retrofit. Base demand = 200W/door

Sources - savings:	Tennant 1992
cost:	Tennant 1992
load shape:	PG&E 1992b
measure life:	Tennant 1992
other:	
Principal contact:	R. Alexander Tennant, Zerowatt, Oakland, CA, (510) 635-3600

R2. Very Low Head Pressure

Food storage refrigeration condensers have historically been designed with a fixed-head pressure high enough to maintain condensation under peak ambient conditions. This practice wastes energy during non-peak conditions. Fixed-head pressure systems are gradually being replaced with floating-head pressure systems which take advantage of reduced ambient temperatures during winter and evening operation by allowing condensing temperatures as low as 70°F. Temperatures are not typically allowed to fall below 70°F, which ensures proper expansion valve operation and to facilitate hot gas defrost.

Recent developments in controls allow very low head pressure with condensing temperatures below 70°F. The temperature is limited only by proper refrigeration cycle operation: 45°F for low- and medium-temperature refrigeration, and 55°F for high-temperature refrigeration. Expansion valves are now available which operate at low pressure differences. Hot gas defrost is retained by adding a control to the defrost timer to temporarily raise the condensing temperature.

In a computer simulation for the New England Electric System, a very low head pressure system demonstrated a 9% savings over a standard floating head pressure supermarket system (EPRI, 1991). Savings in California will be lower but still significant, especially in inland valley climates with wide diurnal temperature ranges (Nugent, 1992). The estimated cost premium for the modifications to floating head pressure is $600 for a large supermarket (EPRI, 1991).

Very low head pressure will need education efforts to convince store operators of system reliability and possible rebate programs to encourage adoption of the technology.

R2. Very Low Head Pressure

Allowing condenser temperature to approach outdoor temperature can show 10% savings.

Market sectors:		COM
End-use:		REF,FREEZ
Market segment:		NEW, RET
Typical unit size:		1 supermarket
Base case -		
Description: Floating head pressure control		
Efficiency:		n/a
Energy use:		496516 kWh/yr
New technology -		
Efficiency:		n/a
Energy use:		450908 kWh/yr
Electricity savings:		45608 kWh/year
Gas savings:		0 therms/year
Percent savings:		9%
Summer demand savings:		0.0 kW
Winter demand savings:		7.2 kW
Interactive effects:		none
Technology cost:	$	600 full
Other costs:	$	0
Commercialization date:		1993
Measure life:		10 years
Technically feasible applications:		100%
Data quality:		B
Cost of saved energy:	$	0.00/kWh
Savings potential:		0.3%
Current status:		COMM
Next steps:		REB
Notes:	Savings are from national numbers - may be lower for CA. Demand = 4W/sf	

Sources - savings:	EPRI 1991
cost:	EPRI 1991
load shape:	PG&E 1992b
measure life:	Nugent 1993
other:	
Principal contact:	none

R3. <u>Supermarket Integration</u>

Although there have been many improvements in supermarket refrigeration case efficiencies in recent years, there remain some emerging technologies that together provide significant potential for further supermarket energy savings. EPRI and major equipment manufacturers are working on improvements in controls, compressors, and case lighting.

Some of the more promising technologies include:

- Controls: Compressor cycling is presently controlled by suction pressure, resulting in large swings in case temperature and added defrost requirements. Electronic compressor controls which sense actual case temperature rather than suction pressure provide closer control at higher efficiency.

- Defrost: Alternatives for improving defrost performance include hot gas defrost and use of frost sensors rather than timers to control electric coil defrost systems.

- Heat Exchangers: Over 50% of case load is latent in the form of frost and condensate. Aluminum heat exchanger coatings which remove moisture from case coils more efficiently can reduce this latent load.

- Compressors: Most supermarket cooling is provided by racks of reciprocating compressors. Scroll and open screw compressors are two potential high-efficiency alternatives. The latter are presently used in Japan, but due to the refrigerant loss inherent in the open compressor design, will require inexpensive non-CFC refrigerants.

- Integration: Another innovation, which eliminates refrigerant distribution losses, is the integration of compressors into the refrigeration case in conjunction with remote outside condensers.

- Case lighting has lagged behind general commercial lighting in efficiency improvements. Case lighting improvements include T-8 lamps, electronic ballasts, ballasts located outside the case, and better controls. These measures not only reduce lighting energy but reduce case loads as well.

Most of these technologies are expected to be commercialized in the next five to ten years. Estimated savings compared to a new 1993 supermarket vary from 30-40% with an estimated cost premium of 10-15% (Nugent, 1993). Because of the extensive design changes necessary, these technologies are only applicable to new and complete retrofits of supermarket refrigeration systems.

More R&D is presently required, but as each technology becomes available, demonstration sites and rebates may be appropriate to speed acceptance.

R3. Supermarket System Integration

Combination of compressor, lighting, and control technologies has 30-40% savings potential

Market sectors:		COM
End-use:		REF,FREEZ
Market segment:		NEW
Typical unit size:		40,000 sqft
Base case -		
Description: Remote recip compressers, floating head pressure, R8 doors		
Efficiency:		n/a
Energy use:		1000000 kWh/yr
New technology -		
Efficiency:		n/a
Energy use:		700000 kWh/yr
Electricity savings:		300000 kWh/year
Gas savings:		0 therms/year
Percent savings:		30%
Summer demand savings:		45.6 kW
Winter demand savings:		39.9 kW
Interactive effects:		F
Technology cost:	$	45000 increnental
Other costs:	$	0
Commercialization date:		1995-2000
Measure life:		10 years
Technically feasible applications:		50%
Data quality:		C
Cost of saved energy:	$	0.02/kWh
Savings potential:		0.5%
Current status:		RES, PROTO
Next steps:		R&D, DEM

Notes: Complete retrofit of 25% of existing stock assumed.

Sources - savings:	Kahtar 1992, Nugent 1993
cost:	Nugent 1993
load shape:	PG&E 1992b
measure life:	Nugent 1993
other:	
Principal contact:	Dennis Nugent, EPRI, Palo Alto, CA, (415) 855-2000

D1. Green Plug Motor Controller

This voltage controller technology can improve the efficiency, power factor, and lifetime of electric motors and appliances in retrofit, new and OEM installations. Appliances are rated to operate between 104 and 127 volts, but often receive voltage in the upper portion of this range. The GreenPlug saves energy by reducing voltage to a setpoint at the minimum level required by the device, about 110 volts for purely resistive loads (lights, heaters) and 104 volts for mostly inductive loads (such as a solenoid). A refrigerator will receive about 106 volts while the compressor is on, and a higher voltage when the defrost heaters or interior lights are on. If the line voltage drops below the setpoint, the GreenPlug passes whatever voltage is available, minus a roughly 1.5-volt drop across the controller itself.

Motors operating on the GreenPlug draw less power below 90% loading but slightly more power above 90% loading. The controller causes motors to run cooler and quieter, because it eliminates surplus magnetizing current. Cooler operation is likely to increase motor life.

Appliance warranties do not preclude the use of the GreenPlug, nor is there reason to expect problems with the device. If a problem arises with a warranted appliance, and the manufacturer suspects that the GreenPlug was responsible, the manufacturer is likely to repair the appliance once and put the consumer on notice that any future problems linked to the GreenPlug will not be covered (Mankowski, 1992).

The GreenPlug inserts into the wall outlet and provides its own three-pronged receptacle for the appliance plug. Maximum load is 3/4 hp. An OEM (hardwire) version is planned for applications such as furnace fans. When applied to refrigerators, the reduced voltage has the following effects: the motor will use less energy, the interior light will be dimmer, and the freezer will run colder because the circulation fan is rotating more slowly. Low utility line voltage from other causes will have the same effects. Tested at 120-V line service, the GreenPlug reduces the energy use of refrigerators by up to 12%, ignoring interior temperature changes, with the largest savings in older, less efficient refrigerators. Tests that hold interior temperatures constant show average savings of 3.5% (Beard, 1992). Savings are 10-15% with furnace fans and 7-21% with washing machines (ETL, 1992). Savings will be greater the higher the utility line voltage.

Unlike power factor controllers (PFC), which sense phase shift and attempt to minimize it, the GreenPlug senses and controls only the level of the voltage applied to the appliance. It has total harmonic distortion of about 28%, mostly in the third harmonic, and raises the true power factor of the motor by 310% over a 20100% range of load.

The GreenPlug will be marketed through hardware stores and other retail outlets beginning in February 1993 ($35 retail, $25 wholesale). Simple paybacks for a $35 GreenPlug used on an average refrigerator will vary from 21 months to 16 years, depending on the level of the line voltage and whether one counts energy saved due to changed interior cabinet temperatures.

Additional laboratory and field testing is needed to confirm savings projections and to judge impact on service quality and appliance life. Utilities should remain cautious about offering rebates for this product until such testing is complete.

D1. Green Plug motor controller

Retrofit voltage controller supplies minimum required voltage to refrigerator motor.

Market sectors:		R&C
End-use:		MOTOR
Market segment:		NEW, RET, OEM
Typical unit size:		1 hp
Base case -		
Description: Typical mid-1990s new 18 cubic foot refrigerator running on 120V.		
Efficiency:		n/a
Energy use:		700 kWh/yr
New technology -		
Efficiency:		n/a
Energy use:		658 kWh/yr
Electricity savings:		42 kWh/year
Gas savings:		0 therms/year
Percent savings:		0.06
Summer demand savings:		0.01 kW
Winter demand savings:		0.01 kW
Interactive effects:		G
Technology cost:	$	35 full
Other costs:	$	0
Commercialization date:		1993
Measure life:		10 years
Technically feasible applications:		100%
Data quality:		A
Cost of saved energy:	$	0.09/kWh
Savings potential:		0.4%
Current status:		PROTO, FLDTEST
Next steps:		DEM

Notes: Savings vary with line voltage. Assumes full penetration if furnace fans, refrig, frzrs, clothes washers. Peak savings based on 6% reduction in refrig. demand.

Sources - savings: Green Technologies 1992; Beard 1992; ETL 1992
cost: Green Technologies 1992
load shape: PG&E 1992a
measure life: Green Technologies 1992
other:

Principal contact: Peter Laehy, Green Technologies, Boulder, CO, (303) 581-9600

D2. Switched Reluctance Drive

The switched reluctance (SR) drive is a compact and efficient brushless, electronically commutated DC motor with high efficiency and torque, variable speed regulation, and simple construction. Available in virtually any size, it will compete for the same kinds of applications as the five-phase motor, but should have an advantage in large sizes or harsh environments. Switched reluctance is an old idea that has advanced recently with progress in solid-state electronics and software.

SR drives and electronically commutated permanent magnet (PM) motors are competing to supplant induction motors in a number of applications. Both are most attractive in new and OEM installations because they come as a motor-controller package. Likely applications include appliances, residential heating and cooling, and commercial HVAC fans and pumps. PM motors have a head start in the market, but the mechanical simplicity of the SR motor is expected to make it very competitive. The SR motor has seen limited use in Europe, primarily in mining. Most SR research and application in the U.S. is in fractional-hp aerospace and precision tasks. Hundreds of thousands of SR drives are used in plotters and automotive cruise controls (Brodski, 1992). Other applications include fans, machine (servo) control, and electric vehicles. General purpose lines are starting to emerge (Lovins and Howe, 1992).

The rugged rotor of an SR motor is much simpler than that of other motors, since it has no field coils or embedded magnetic materials. This simplicity enables some models to operate at speeds up to 50,000 rpm. Although speeds this high are possible with PM and other dc motors, the coils and magnets attached to the rotor are subjected to very high stresses, necessitating more complex designs. Because of its simplicity, the SR motor in mass production should cost no more than, and perhaps less than, mass-produced induction motor/ASD packages of comparable size (Lawrenson, 1992; Brodski, 1992; Hendershott, 1992). Little data is available on the cost of ASDs when incorporated in mass produced OEM products. One source claims that the integration of ASDs into mass-produced Japanese heat pumps adds only $25/hp to the manufacturers cost (Abbate, 1988). We assume a retail price premium of $40/hp for ASDs in high-volume OEM products and assume that the SR drive will have a comparable $40/hp price premium over induction motors without ASDs. This estimate is highly uncertain.

Both torque and efficiency are, in general, higher in SR drives (motor and controls) than in induction motors with ASDs. The current generation SR drives have relatively flat efficiency curves with maximum efficiencies typically above 91% in integral-hp models and 80% in fractional-hp units. Efficiency drops less than 10 percentage points from full load to light load, compared to a 1520 point drop across a similar load range for induction motors with speed control. The efficiency margin of SR motors is most dramatic in the small frame sizes (under 5 hp). For instance, a 3.5 hp switched reluctance motor has been designed with an efficiency of 93% (Lawrenson, 1992). The most efficient induction motors in this size range are roughly 90% efficient and would be at least a point or two points less efficient if coupled to an ASD.

The primary technical challenge facing SR motor technology is its complex engineering and design. It will take time and encouragement from the marketplace to spread SR technical know-how. The development effort is primarily through manufacturers, OEMs, and EPRI-funded R&D. Commercial models are available on a custom basis for demonstrations. Rebate programs would be premature, but utility-funded demonstrations would be appropriate.

D2. Switched reluctance drive

Improved electronically commutated dc motor.

Market sectors:		ALL
End-use:		MOTOR
Market segment:		OEM
Typical unit size:		5 hp
Base case -		
Description:		5 hp standard-efficiency HVAC motor running 1,500 hours/year.
Efficiency:		85 %
Energy use:		6582 kwh/yr
New technology -		
Efficiency:		93 %
Energy use:		6016 kWh/yr
Electricity savings:		566 kWh/year
Gas savings:		0 therms/year
Percent savings:		0.054
Summer demand savings:		0.2 kW
Winter demand savings:		0.02 kW
Interactive effects:		none
Technology cost:	$	200 incremental
Other costs:	$	0
Commercialization date:		1992
Measure life:		10 years
Technically feasible applications:		80%
Data quality:		B
Cost of saved energy:	$	0.05/kWh
Savings potential:		1.5%
Current status:		COMM
Next steps:		DEM
Notes:		Savings potential based on 80% penetration and 5% energy reduction in home appliances and comm. HVAC.

Sources - savings:	Lawrenson 1992; Hedershott 1992
cost:	Lawrenson 1992; Brodski 1992; Hedershott 1992
load shape:	PG&E 1992b
measure life:	Lawrenson 1992
other:	Banerjee 1992
Principal contact:	Peter Lawrenson, Switched Reluctance Drives, Leeds, UK, 44.532.443.844

D3. Five-Phase Synchronous Motors

Five-phase permanent magnet synchronous motors are under development through an EPRI project with McCleer Power Company and the University of Tennessee at Knoxville. The basic concept is to innovate beyond standard one- and three-phase systems by using modern electronic controls to develop multi-phase drives and motors.

Motors using more than three phases exploit ongoing improvements in solid state technology and embedded controls to improve motor performance and efficiency. Moving beyond three phases offers a number of benefits:

- By using more phases, current can be distributed to a greater number of smaller, less expensive, and more reliable power electronic components.

- Since current through each phase is reduced, the copper conductor and windings can be of a smaller and easier to handle gauge.

- Peak currents are lower for each phase, thereby improving switching controllability and reducing the stress on any one phase.

- More phases allow a more uniform magnetic field distribution inside the motor, improving interaction with the rotor's permanent magnets, and thereby dramatically improving efficiency. Five to seven phases is the optimum number for these motors; fringing effects at the edges of the magnets make more than that ineffective.

- Improved and efficient use of the rotor's magnetic fields allows the use of simple, inexpensive ceramic magnets, thereby reducing cost and avoiding the complicated manufacturing issues associated with advanced magnet materials.

Early designs exist for both standard cylinder (radial gap) shapes and innovative pancake (axial gap) designs in sizes ranging from fractional-hp to over 100—hp. Both designs show remarkable efficiency curves. A 10 hp machine rated at 3,600 rpm boasts an energy efficiency of 88% at 20% speed (720 rpm) and over 93% efficiency from 40% (1,440 rpm) up to rated speed (McCleer, 1991). Peak efficiency exceeds 95%. Induction motors and standard electronically commutated permanent magnet motors in this size rarely have *peak* efficiencies above 90%.

These motors are expected to cost slightly more to manufacture than comparably sized induction motors due to the permanent magnet materials required for the rotor. However, their controls will probably cost less than ASDs, making the cost of a complete five-phase drive system comparable to the cost of a high-efficiency induction motor and ASD system (McCleer, 1993). As with the switched reluctance motor, we assume a $40/hp price premium over induction motors without speed control. This estimate is highly uncertain.

The flexible size and shape of these motors make them attractive for a wide variety of uses. They will compete for many of the same applications as switched reluctance motors, although switched reluctance is likely to have an advantage in large sizes and harsh environments. Early applications are expected in a broad range of commercial and residential uses including appliances and HVAC. Early demonstration projects are hand tools and small utility vehicles like golf carts. Commercialization of five-phase motors is expected in 1994 to 1995 (Douglas, 1992).

D3. Five Phase Motors

Improved permanent magnet dc motor.

Market sectors:		ALL
End-use:		MOTOR
Market segment:		NEW, ROB, OEM
Typical unit size:		5 hp
Base case -		
Description:	5 hp standard-efficiency induction motor running 1,500 hours/year.	
Efficiency:		85 %
Energy use:		6582 kwh/yr
New technology -		
Efficiency:		93 %
Energy use:		6016 kWh/yr
Electricity savings:		566 kWh/year
Gas savings:		0 therms/year
Percent savings:		0.054
Summer demand savings:		0.2 kW
Winter demand savings:		0.02 kW
Interactive effects:		none
Technology cost:	$	200 incremental
Other costs:	$	0
Commercialization date:		1994-1995
Measure life:		10 years
Technically feasible applications:		80%
Data quality:		B
Cost of saved energy:	$	0.05/kWh
Savings potential:		1.5%
Current status:		PROTO
Next steps:		DEM
Notes:	Savings potential based on 80% penetration in residential motors and-comm. HVAC.	

Sources - savings:	McCleer Power 1993
cost:	McCleer Power 1993
load shape:	PG&E 1992b
measure life:	EPRI 1992
other:	EPRI 1992
Principal contact:	Ben Banerjee, EPRI, Palo Alto, CA (415) 855-2000

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O1. Low-Energy Desktop PC

Available models of desktop PCs have widely varying levels of power consumption, ranging from more than 200 W down to about 30 W. It appears that present average power consumption is about 132 W per unit (Norford et.al., 1990). Although energy use per instruction execution capability has fallen by two to three orders of magnitude since the 1960s, average power consumption per PC has stayed the same or risen because of the huge increases in computing power in the average machine (Shepard et. al., 1990). Furthermore, analysis has shown that about 60-70% of PC energy consumption occurs when the machines are not being used (Newsham and Tiller, 1992). Machines are frequently left on overnight, or left on for extended periods during the day when not being used. Power management can eliminate this energy waste.

In contrast to currently available desktop PCs, laptop computers typically consume about an order of magnitude less power. Technologies such as liquid crystal display (LCD) screens, low-power-consumption disk drives, CMOS chips, and power management features have enabled designers to build machines with high computing power but low power consumption. Many of these technologies are applicable to desktop PCs, and may pave the way to much more efficient desktop machines. Depending on whether strong market demand for energy efficiency materializes, efficient hardware technologies that may appear in desktop machines include the SL chip (which can go into a very low-power rest state and them resume activity where it was left off without rebooting), improved drives, and advanced flat panel displays.

The U.S. EPA hopes to tap into the potential for desktop PC power management savings with its new Energy Star Computer Program. The program allows computer manufacturers to use a special EPA logo to promote machines that are capable of going into a "low power state of 30 watts or less" (Zoi, 1992).

A combination of power management and adaptation of laptop-type hardware improvements should enable average desktop power consumption during typical operating hours to be reduced to about 20 W with an active matrix color display and to about 55 W using a color cathode ray tube (CRT) display; these numbers are substantially above the power requirements of present laptops because they assume much larger displays -- 15 in. -- than are presently used in laptops (Norford 1992). With the exception of advanced flat panel display modifications, all hardware and power management improvements are expected to have little or no costs (Zoi, 1992). Desktop LCDs are currently four to five times more expensive than CRTs of the same size, but increasing production volumes are estimated to reduce incremental costs to between several hundred dollars and $0 within a few years (Ledbetter and Smith, 1993). Commercialization of power management and laptop type hardware and software features is expected in 1993. For the purposes of this report, two analyses were performed for this technology - one analyzing the use of power management and hardware modifications with a CRT and one analyzing the use of power management with an active matrix LCD.

Utilities should consider sponsoring demonstration projects and other educational activities to promote the use of low-energy desktop PCs.

01a. Low-energy desktop PC (w/LCD display)

Desktop PC with power management/flat screen display

Market sectors:		R&C
End-use:		C: OFFEQ; R: MISC
Market segment:		NEW, ROB
Typical unit size:		1 PC
Base case -		
Description: 386-base machine		
Efficiency:		132 watts (average)
Energy use:		330 kWh/yr
New technology -		
Efficiency:		20 watts (average)
Energy use:		50 kWh/yr
Electricity savings:		280 kWh/year
Gas savings:		0 therms/year
Percent savings:		85%
Summer demand savings:		0.24 kW
Winter demand savings:		0.16 kW
Interactive effects:		A, B, C, G
Technology cost:	$	0-200 incremental
Other costs:	$	0
Commercialization date:		1995-2000
Measure life:		5 years
Technically feasible applications:		100%
Data quality:		A
Cost of saved energy:	$	0-0.12/kWh
Savings potential:		1.0%
Current status:		RES, PROTO
Next steps:		DEM, ED

Notes: Assumes color active matrix LCD; commercial sector energy usage increased by 25% to account for residential sector

Sources - savings: Piette et al. 1991, Norford et al. 1990
cost: Zoi 1992
load shape: Piette et al. 1991
measure life: Norford 1992
other: n/a

Principal contact: Les Norford, MIT, Cambridge, MA (617) 253 -7628

01b. Low-energy desktop PC (without LCD)

Desktop PC with power management/CRT display

Market sectors:		R&C
End-use:		C: OFFEQ; R: MISC
Market segment:		NEW, ROB
Typical unit size:		1 PC
Base case –		
Description: 386-base machine		
Efficiency:		132 watts (average)
Energy use:		330 kWh/yr
New technology –		
Efficiency:		55 watts (average)
Energy use:		137.5 kWh/yr
Electricity savings:		193 kWh/year
Gas savings:		0 therms/year
Percent savings:		58%
Summer demand savings:		0.16 kW
Winter demand savings:		0.11 kW
Interactive effects:		A, B, C, G
Technology cost:	$	0 incremental
Other costs:	$	0
Commercialization date:		1993
Measure life:		5 years
Technically feasible applications:		100%
Data quality:		A
Cost of saved energy:	$	0.00/kWh
Savings potential:		0.7%
Current status:		RES, PROTO
Next steps:		DEM, ED

Notes: Commercial sector energy use increased by 25% to account for residential

Sources – savings:	Davis 1992
cost:	Zoi 1992
load shape:	Piette et al. 1991
measure life:	Norford 1992
other:	n/a
Principal contact:	Les Norford, MIT, Cambridge, MA (617) 253 -7628

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O2. Improved Inkjet Printers and Faxes

Commercially available printer and fax machine technologies have a wide variety of energy consumption characteristics. At present, inkjet technology is the most energy-efficient commercial technology for printers and faxes.

Inkjet machines rely on print heads that spray ink on paper from tiny, electronically activated orifices. When compared with the more popular laser printers and faxes, the primary disadvantages of inkjet technology are print speed and quality. Continuing improvements in printhead design, use of multiple printheads, and image smoothing capability should enable these machines to compete for print quality and speed within a couple of years. Color inkjet printers are presently comparable in speed and quality to color laser printers; PC Magazine reviewers stated that "you need a magnifying glass to detect the difference between text samples printed on this (the Hewlett-Packard PaintJet XL300) and a LaserJet" (PC Magazine, 1992). When combined with their very simple design, reliability, and lower than laser technology cost, inkjet machines should prove attractive.

Inkjet printers printing and standby power consumption are typically less than 30 W and 10 W, respectively, as compared to laser machines typically consuming more than 500 W and 50 W, respectively (Ledbetter and Smith, 1993). The machines are significantly lower in cost than laser machines, but a direct comparison is not appropriate as the features of machines utilizing the two technologies are markedly different.

Inkjet machines are currently gaining in the lower end of the market (in terms of print speed and quality), largely due to their low cost. They are expected to continue gaining market share as their speed and print quality improve (Nordman, 1993). Strong measures are probably not needed to promote use of these machines, but some targeted demonstrations and education would be useful.

O2. Improved inkjet and bubblejet printers/faxes

improved speed and quality

Market sectors:	R&C
End-use:	C: OFFEQ; R: MISC
Market segment:	NEW, ROB
Typical unit size:	1 printer/fax
Base case -	
Description:	laser printer/thermal fax
Efficiency:	P:132, F:30 watts (average)
Energy use:	P:300, F:250 kWh/yr
New technology -	
Efficiency:	P:26, F:14 watts (average)
Energy use:	P:61, F:120 kWh/yr
Electricity savings:	P:239, F:130 kWh/year
Gas savings:	0 therms/year
Percent savings:	P:80%, F:52%
Summer demand savings:	P:0.042, F:0.056 kW
Winter demand savings:	P:0.042, F:0.056 kW
Interactive effects:	A, B, C, G
Technology cost:	$ negative incremental
Other costs:	$ varies
Commercialization date:	1993-1994
Measure life:	5 years
Technically feasible applications:	90%
Data quality:	A
Cost of saved energy:	$ negative/kWh
Savings potential:	0.7%
Current status:	RES
Next steps:	DEM, ED
Notes:	Commercial sector energy use increased by 25% to account for residential
Sources - savings:	Piette et al. 1991, Shepard 1990
cost:	Norford 1992
load shape:	Piette et al. 1991
measure life:	Norford 1992
other:	n/a
Principal contact:	Les Norford, MIT, Cambridge, MA (617) 253 -7628

O3. Improved Cold-Fusing and Low-Energy Fusing Copiers, Printers, and Faxes

Most imaging office equipment that use a xerographic processes, such as copiers, laser printers, and laser fax machines, use a hot fuser to fix an image to paper. High temperatures (>300 degrees F) are required in the fuser element to fuse toner to paper. Such high temperature demands have meant high-power fuser elements, which for a typical mid-range, floor-mounted photocopier can exceed 1000 W during copying. The fuser element is by far the biggest energy user in these machines (Norford 1992).

Technologies exist that could substantially reduce this component of a machine's power consumption. Cold pressure fusing (which fuses toner to paper with high-pressure rollers), and Delphax ion-deposition imaging (which uses an entirely different process for forming an image on the image drum, which is then cold pressure fused to paper), eliminate the need for a hot fuser. Alternatively, use of infrared or microwave heating could be used to directly heat a small zone rather than an entire fuser roller; or thin-belt fusers with much less mass than print drums used in present-day machines could dramatically reduce energy requirements for hot fuser printing (Ledbetter and Smith, 1993).

Cold pressure fusing is already commercially available, but has limitations in that images tend not to adhere as well to paper as hot-fused images. Therefore, the technology needs improvement before wide-scale application is possible. Delphax technology is also currently available, but is presently used only in high volume printing machines. Technologies other than cold pressure fusing and Delphax will require more time for development before they can be commercialized.

Technology costs for all of these options are uncertain, but are likely to be low. For Delphax ion-deposition imaging as presently used in high volume printing machines, the technology is highly cost-competitive with other high volume machines (Ledbetter and Smith, 1993). If it could be successfully scaled down to lower volume machines, it might retain its cost competitive advantage.

Several types of efforts would help speed the introduction and increase the application of these technologies, including R&D and Golden Carrot programs.

O3. Improved cold-fusing/low energy fusing copiers/printers/faxes

Technologies for xerography which use less energy

Market sectors:	R&C
End-use:	C: OFFEQ; R: MISC
Market segment:	NEW, ROB
Typical unit size:	1 each
Base case -	
Description:	heat and pressure fusing machines
Efficiency:	C:200, P:132, F:30 watts (average)
Energy use:	C:468, P:309, F:262 kWh/yr
New technology -	
Efficiency:	C:100, P:66, F:15 watts (average)
Energy use:	C:234, P:155, F:130 kWh/yr
Electricity savings:	C:234, P:154, F:130 kWh/year
Gas savings:	0 therms/year
Percent savings:	C:50%, P:50%, F:50%
Summer demand savings:	C:100, P:25, F:35 kW
Winter demand savings:	C:100, P:26, F:35 kW
Interactive effects:	A, B, C, G
Technology cost:	$ 0 incremental
Other costs:	$ 0
Commercialization date:	1991-1996
Measure life:	5 years
Technically feasible applications:	100%
Data quality:	B
Cost of saved energy:	$ 0.00/kWh
Savings potential:	0.7%
Current status:	RES, COMM
Next steps:	GC
Notes:	Commercial sector energy use increased by 25% to account for residential
Sources - savings:	Piette et al. 1991
cost:	Shepard et al. 1990
load shape:	Piette et al. 1991
measure life:	Norford 1992
other:	n/a
Principal contact:	Les Norford, MIT, Cambridge, MA (617) 253 -7628

M1. Ozonated Commercial Laundering

A Florida firm (Tri-O-Clean) has developed a commercial laundering system that uses no detergent, operates in cold water, and recycles most of the water used in the process. The system eliminates detergent by saturating the wash water with ozone, a powerful oxidant that is widely used to disinfect drinking and swimming pool water. Two other manufacturers Laundry Logic and Pure Water Corporation offer ozonation systems as an enhancement to conventional laundering, but do not claim to eliminate water heating or the need for detergent. We focus on the Tri-O-Clean system because of its dramatic claims of energy and water savings, which require independent verification.

Tri-O-Clean leases ozonation equipment, pumps, and filters to provide ozonated water to the laundry's existing washers. Without detergent, rinse cycles are eliminated, cycle time is reduced, and pollutant discharges are virtually eliminated. Small amounts of bleach are used for some types of laundry. Water from the washer is recovered, filtered, recharged with ozone, and reused for washing. The closed-loop system reportedly keeps ambient ozone levels below 0.01 ppm, well below the EPA's 0.1 ppm 8-hour exposure limit.

The system can clean lightly- to moderately-soiled goods, which represent about 80% of the volume in commercial laundering. Heavily soiled items can use a combination of ozonated water and detergents.

Prototype installations are operating in a 500-inmate prison and in the Marriott Hotels in Jacksonville and Orlando, Florida. Each facility reports good results, including reduced water, energy, detergent, and sewage costs, extended fabric life, reduced laundering time, and good cleaning. The Jacksonville Marriott runs its day shift on ozone in cold water with no detergent and saves heavily soiled items for the night shift where it uses ozone and half the typical amount of detergent in 114°F water instead of the 145°F water used previously. The hotel is saving $1800/month on water and energy, has shut off all four water heaters during the day shift, and runs only one water heater for the evening shift. Since the hotels wash mostly white items and the prison has a lot of blues and greys that may not show soil very well, the quality of washing performance for a full range of colors and fabric types remains uncertain.

The manufacturer structures its leases to reduce laundry operating costs by 20%. The minimum economic size serves a 200-room hotel. Water heating, usually supplied by natural gas, is dramatically reduced, but peak electricity demand increases to run pumps and ozonating equipment. Total electricity consumption may be unchanged, however, since the washer motors and pumps run less time to serve the same cleaning load. No measured energy use data are available. A 100 gallon per minute system, large enough to serve a 350-room hotel, draws about 20 kW, 85% for pumps needed to circulate water through the storage and recycling loop, and the rest for the ozonating equipment (Bladen, 1992). Because the manufacturer will not release information on what it would cost to purchase the equipment, it is difficult to determine the Cost of Saved Energy.

If the manufacturers' claims prove to be true and are broadly applicable, this technology could revolutionize commercial laundering. The water and waste-water savings should be particularly attractive to drought-prone California. Careful third-party evaluations of this technology are necessary to verify long-term cleaning performance, maintenance requirements and lifetime for the ozonation and filtering equipment, and impact on fabric life. Costs-effectiveness outside the lease framework should be determined.

M1. Ozonated commercial laundering

Cold ozontated water without detergent yields energy savings of at least 50%.

Market sectors:	COM
End-use:	CLOWAS
Market segment:	RET, NEW, ROB
Typical unit size:	150 Pounds of dry laundry
Base case -	
Description:	Conventional commercial washing machines
Efficiency:	2160 Btu/lb of laundry
Energy use:	324000 Btu
New technology -	
Efficiency:	510 Btu/lb of laundry
Energy use:	76500 Btu
Electricity savings:	0 kWh/year
Gas savings:	247,500 therms/year
Percent savings:	0.71
Summer demand savings:	0 kW
Winter demand savings:	0 kW
Interactive effects:	H
Technology cost:	$not available
Other costs:	$ additional maintenance
Commercialization date:	1992
Measure life:	10 years
Technically feasible applications:	80%
Data quality:	C
Cost of saved energy:	$not available/
Savings potential:	1.9%
Current status:	FLDTEST, COMM
Next steps:	R&D, DEM
Notes:	Saves gas, may increase electric use. 71% savings is weighted avg. of 76% savings on 80% of items, 50% on remainder.
Sources - savings:	Bladen 1992; Moore 1992
cost:	Bladen 1992
load shape:	Bladen 1992
measure life:	Bladen 1992
other:	
Principal contact:	Don Bladen, O3Tech, Fort Pierce, FL, (407) 595-6500

Chapter 3

OTHER EMERGING TECHNOLOGIES

This chapter provides brief descriptions of the emerging technologies whose levelized cost was too high or energy savings were too low to pass the screening criteria for medium and high priority measures (these criteria are discussed in Chapter 1). Technologies are listed by end-use in the following order: appliances, lighting, building shell, space heating and cooling, water heating, motors, office equipment, commercial cooking, and miscellaneous.

APPLIANCES

A12. Direct-Drive Washing Machine with PSC Motor

In a conventional washing machine the motor is connected to the washtub with a belt and transmission system. The transmission system allows the washer to switch direction during the agitation cycle. A promising alternative is to directly connect the motor to the tub, and to use a permanent split capacitor motor which can vary motor speed and reverse direction. Machines with this feature have been developed by Hitachi (sold in Japan) and Whirlpool (sold in Latin America and soon to be introduced to the U.S). The Raytheon Corporation developed a system of this type for Speed Queen that Speed Queen is now considering. This system reduces motor energy use by about 10%. By eliminating the belt, and perhaps the transmission, this approach should improve washer reliability (belt and transmission problems are a major source of washer breakdowns). Costs for this measure are likely to be modest because savings in belt and transmission costs help offset the cost of more expensive motors. However, since the vast majority of clothes washer energy goes to heat water (approximately 90%), and not power the motor (approximately 10%), overall savings from this measure are limited (Clawson 1992).

A13. Gas Steam Convection Oven

The Gas Research Institute, working with the Arthur D. Little Company, has developed a gas steam convection oven that uses gas to cook food in approximately the same amount of time as a microwave oven. Two prototype units were developed: a countertop oven, and a full size oven. The prime impetus for the work was to compete with the microwave oven on the basis of cooking time. Cooking quality with this oven is reportedly excellent (McFadden et al. 1991). Energy savings were not measured, but are estimated by one of the lead researchers on this project to be 20-40% relative to a conventional full size oven (McFadden 1992). General Electric considered producing a full size oven with this feature, but due to the recession, backed off. A full size oven with this feature would be a premium-priced product, costing perhaps $1000-1500, far more than the $400-500 price of a standard gas oven. There may be ways to lower this cost by sacrificing some of the energy savings (McFadden 1992). However, given the high cost and the limited energy savings, this technology is likely to be driven by cooking time and cooking quality considerations, not energy savings.

A14. Residential Infrared Gas Impingement Burner

In the early 1980s the Gas Research Institute conducted extensive work to develop a residential infrared gas impingement burner. These burners use approximately 30% less gas than conventional burners (GRI 1984). Ultimately the burner proved to be too expensive for residential applications (Hemphill 1992), but a commercial version will soon be introduced, as discussed under CC6 below. The company that is making this commercial burner, Wolf Range, will introduce a residential version in 1994. However, Wolf Range produces only premium residential ranges with list prices of $3000 and up. Wolf Range estimates that two infrared burners will add at least $500 to the cost of a residential range (Bender 1992). Due to the high cost of this range, it is likely to be a niche product with limited sales and hence limited energy savings. However, in the long-term these burners may receive more attention, as they significantly reduce emissions of nitrogen oxides, and hence improve indoor air quality (GRI 1984).

A15. DC Wiring and Appliances

Research at the Lawrence Berkeley Laboratory (Meier 1992) indicates that residential electricity use can be reduced by approximately 10-20% if homes are wired with DC wires to complement the existing AC wiring system. DC current has lower line losses than AC current. Furthermore, DC power can be directly used to operate battery chargers (used to recharge many cordless appliances) and to operate variable speed appliances (not presently widespread, but variable-speed air conditioners, heat pumps, and washing machines are now on the market and other appliances may follow soon). By using DC power directly for this equipment, transformer losses are reduced since one whole-house transformer will be more efficient than many little transformers. This measure is most applicable for photovoltaic powered houses, where the cost of the additional wiring is likely to be offset by savings in photovoltaic panel costs. For grid-connected houses, the cost of the second wiring system, even in new construction, is likely to be too high to be justified by the energy savings.

LIGHTING

L16. Eight Foot T8 Fluorescent

Four foot T8 fluorescents lamps are currently increasing in market share relative to standard T12 lamps due to their increased efficiency and utility rebate programs which promote their use. T8 lamps are 1" in diameter as compared to 1.5" for T12 lamps; the smaller diameter allows for more efficient operation due to the reduction in optical losses. Lower efficiency, cool white, eight foot T8 lamps have been commercially available for years; Sylvania recently introduced a high efficiency tri-phosphor 8' Octron lamp with lamp efficacies similar to their 4' lamps (Shinn, 1992). However, conversion from energy-saving 60W 8' T12 lamps with an electronic ballast to T8 lamps yields only a 6-7% energy savings, as opposed to a roughly 17% savings for four foot lamps (Lally, 1992). Additionally, 8' lamps represent only 40% of installed fluorescent watts (Nadel et al., 1989); this small market share plus the limited energy savings yield an insignificant savings impact.

L17. Isotope Enrichment

The addition of enriched isotopes to mercury fill gas in fluorescent lamps can increase lamp efficacy by 2-3%. Both GE and Sylvania performed preliminary research on the technology in the late 1980s, but abandoned research efforts due to the relatively small energy savings gain (McGowan, 1992 and Shinn, 1992). Ultra Centrifuge Nederland of The Netherlands has begun marketing the use of enriched Mercury-196 in place of natural mercury in lamps, claiming a 3-5% savings (Potts, 1992). However, it appears that the technology will not be further developed because the increased cost of Mercury -196 does not justify the limited savings. Unless theoretical investigation uncovers a further advance that will improve energy savings or decrease costs, lamp manufacturers will not have sufficient incentive to convert existing lamp manufacturing practices.

L18. 36W T8 Fluorescent Lamps

Osram introduced a modified version of their European 36W four foot T8 lamp and electronic ballast system into the US market in mid-1992. The system provides 3450 lumens per lamp with an approximately 30% lumen increase as compared to a standard 32W T8 four foot lamp. The 36W lamp is designed to replace/retrofit high output four foot T12 lamp systems, or to maintain light levels when delamping. Osram also recommends the lamps for 8' T12 retrofits. The lamp efficacy is roughly equivalent to standard 32W T8 (Weidmark, 1992). Philips has a similar product whose distribution is limited to Europe (Lally, 1992). However, the technology has limited applicability in both the high output and 8' retrofit markets. High output lamps account for only 4% of the fluorescent lamp market, hence are not a significant area of savings. Additionally, inherent light distribution problems with delamping can also occur with use of the 36W lamp.

L19. Energy-saving T10 Fluorescent Lamp

Similar to T8 lamps, T10 fluorescent lamps theoretically afford increased lamp efficacy over standard T12 lamps due to the reduction in optical losses from the smaller lamp diameter. T10 lamps can operate with any T12 ballast, and as such may be attractive for retrofit of existing T12 systems (Lally, 1992). Panasonic announced a 36WT10 in 1989 but has not commercialized it, as market potential is limited. The lamp has a higher lumen output than a 34W lamp, and can operate at lower temperatures (Baba, 1992). The potential for savings from a T10 retrofit application is limited to situations where energy-saver 34W T12 lamps cannot be used due to their decreased lumen output and/or where temperatures below 60 degrees F occur.

L20. Three-Way Compact Fluorescent Lamp

A three-way compact fluorescent lamp (CFL) system has two or three CFLs and one or more ballasts such that the fixture can operate a single or multiple lamp simultaneously. Thus, the system provides three different light output levels, similar to a three-way incandescent lamp. Mitor Industries of Mankato, MN is currently producing a table lamp with three 13W CFLs for residential and commercial markets (Johnson, 1992). Currently, three-way incandescent lamps are approximately 4% of the incandescent lamp market share (Department of Commerce, 1988). Given this small market share, three-way CFLs have a limited overall savings potential.

L21. HID Reflector Lamp

Several manufacturers introduced high efficiency metal halide or high color rendering high pressure sodium lamps to replace high wattage incandescent reflector lamps in 1992. GE and Philips both have a 70W high pressure sodium for use in residential floodlighting. GE additionally has a 150W metal halide PAR 64 designed to replace 300-500W incandescents for general floodlighting, and a 1000W metal halide PAR for sports and stage/studio lighting (GE, 1992). Philips has a 175W metal halide PAR 38 (Philips, 1992). Sylvania has 70 and 100W metal halide PAR lamps designed to replace high wattage (300-500W) incandescents in high ceiling applications (Shinn, 1992). The lamp cost is only slightly higher than standard HID lamps of comparable wattages. However, sales of these lamps is likely to be small, given the small number of high wattage reflector lamps sold in relation to all incandescents.

L22. HID Electronic Ballasts

Electronic ballasts for high intensity discharge (HID) lamps have been commercially introduced within the past year by several manufacturers. Electronic ballasts can improve HID fixture efficacy by approximately 15%. Osram currently produces an electronic ballast for use with its 70W double-ended metal halide lamp at 120V; a 277V version, as well as a ballast for use with their 150W lamp, are expected to be available in 1993 (Weidmark, 1992). ETTA Industries produces an electronic ballast for use with 50 and 100W Iwasaki Daylux high color rendering high pressure sodium lamps. The ballasts are slightly higher in cost then electromagnetic HID ballasts, and have the added advantages of minimizing color shift over time and extending lamp life (ETTA, 1992). Advance is currently developing an electronic HID ballast line, which they expect to introduce in 1993. It will primarily focus on low wattage metal halide lamps, and then expand to higher wattages and high pressure sodium (Benson, 1992). The potential for savings from electronic HID ballasts is limited, however, given the relatively small portion of lighting load supplied by HID sources.

L23. Dimmable HID Ballast

Holophane, GE, and Advance are currently producing ballasts for bi-level lighting controls. Holophane has an integrated lamp/ballast/dimmer control system for both metal halide and high pressure sodium. The dimmer can also be tied in with a photocell for maximum use of daylighting. Switching to 50 or 65% of full energy is available, with light output at slightly lower corresponding levels, i.e. lumens per watt is lower when dimmed (Hughes, 1992).

No full-range dimming ballasts are currently available for use with metal halide and high pressure sodium lamps. Advance anticipates developing dimming ballasts after introduction of electronic ballasts, but does not expect market introduction before 1994 (Benson, 1992).

While HID dimming appears to be cost-effective when dimming is required and used a significant portion of the time, its applications are quite limited. HID sources are generally used in spaces where dimming is not appropriate (i.e. exterior, warehouses, gymnasiums, etc.). Therefore, its application would likely be limited to spaces with indirect and/or color-corrected HID lighting.

L24. Light Engine

Fiber optics and light pipes are currently used for daylight transmission in Japan and several U.S. demonstration projects. GE's Light Engine uses fiber optic light transmission with a central efficient light source. Their prototype system, introduced at LightFair, has a 60W instant-start metal halide lamp with an electronic ballast. The company is targeting the product for use in theatrical applications, store designs, transportation, medical, and a variety of signage applications (GE, 1992). 3M produces several film materials for use in light pipes; they are currently used primarily with central metal halide or halogen light sources. Filters can be used to create a wide variety of color renditions (3M, 1992).

The advantages to these systems are primarily in reduced maintenance costs, as there are fewer electrical components to maintain. The systems are targeted at architectural applications as well as hard-to-reach and hazardous locations for the benefits of reduced maintenance and flexibility in location of the light source and accompanying electrical components (3M, 1992). The systems can have energy savings when used in applications where color is critical and where an efficient central light source is distributed through a filtered transmission system as a substitute for incandescent lighting. However, there are no energy savings in the majority of system applications, as lighting engine system efficacy is below that of individual fixtures using the same light source.

L25. Advanced Daylighting Shelves

Light shelves operate by reflecting light at the perimeter of a building off walls and/or ceilings to provide daylighting deeper into the building core. Manufacturers and designers have recently experimented with tracking shelves, which adjust with changing angles, variable area controls for shelves, and improved optical surfaces. 3M currently produces a variety of reflective films for use in shelves. At current costs, the shelves are generally not cost-effective, as daylight distribution is limited to within approximately 20 feet of the building perimeter, thus displacing only a portion of artificial light in the space (LBL, 1992).

L26. Directional Skylights

Manufacturers are currently developing more sophisticated skylights to maximize daylight in interior building spaces. Tracking skylights generally operate with moveable vertical reflector surfaces and horizontal rotation to maximize daylight efficiency. The angles of reflectance are controlled by sensors and/or timers. Units are currently being field-tested by Illumination Controls Systems of Indialantic, Florida. Their 'SunSeeker' skylight has 31.5 ft^2 of reflective surface and requires no external power for reflector movement or rotation; all sensors and motors are powered by a photovoltaic panel on the top of the unit. In initial testing, the unit has been shown to provide a minimum of 30 footcandles across 1500 ft^2 with typical ceiling heights during average seasonal conditions. The unit costs $2500 plus installation (Webster, 1992). At this price, the unit is only cost-effective when displacing incandescent sources. Therefore, it will likely be installed only when there are overriding aesthetic/color concerns. The integration of space heating devices in the units, which is planned within the next few years, may increase cost-effectiveness; for the near term, however, economics will be marginal and applications will thus be limited.

BUILDING SHELL

S2. Engineered Wall Framing

Most residential walls in California are constructed of 2x4 wood studs placed on 16" centers. As an insulator, framing lumber is one-third as effective as fiberglass batts, providing a "thermal short" in the insulation. Although Title 24 calculations assume a 15% framing factor (the fraction of gross wall area that is framing), a more detailed accounting of sills, corners, and headers more than doubles this estimate to 35% (Davis Energy Group, 1992). Engineered wall framing (EWF) can improve insulation value in two ways: by using fewer, improved load-bearing members and/or by using wood framing with a foam thermal break. An I-beam stud is produced by Barrier System (Brod, 1992) and a T-stud is being developed by TrusJoint MacMillan (Spickler 1992). Installed costs should be comparable to conventional framing methods. Implementation of EWF could be accelerated with utility-sponsored demonstration projects and educational activities directed at builders and home-buyers. Potential energy savings were below the threshold because this technology is applicable to new construction only.

S3. Gas-Filled Panels

Residential exterior walls framed with 2x4's or 2x6's are limited to R-13 and R-21 insulation values, respectively, if filled with conventional fiberglass batts. To increase thermal resistance, builders must either increase wall thickness (increasing cost and complicating design) or use improved insulating materials. An alternative enhanced insulation under development is the gas-filled panel (GFP), a pillow-like assembly that develops high R-values from multiple reflective air spaces. Each unit consists of a barrier envelope containing an inert gas at atmospheric pressure and multiple baffles of thin, low-emissivity sheets which effectively eliminate radiative and convective heat transfer. First-generation prototypes have measured R-values of 5.2/in (air), 7.1/in (argon), and 12.5/in (krypton). For 3.5"-thick panels the estimated cost is approximately $0.42/sq ft (air, R-19), $0.63/sq ft (argon, R-22), and $4.30/sq ft (krypton, R-41) (Griffith, 1992). In comparison, R-11 fiberglass costs $0.24/sq ft with installation costs being similar for both types of insulation. Fabrication and testing of GFP's in conventionally framed walls is the next step for this technology. Potential energy savings were below the threshold because this technology is applicable to new construction only.

S4. Powder-Evacuated Panels

Like gas-filled panels (see S3), powder-evacuated panels (PEP) offer a substitute for conventional wall insulation, but are still in the development stage. The product consists of an evacuated (1-100 torr) R-20/in panel containing a fine powder which provides structural support against atmospheric pressure and limits convective transfer by residual gas. Most discussion of powder/vacuum insulation focuses on appliance (refrigeration, water heat), and specialty uses (scientific and medical equipment). Structural insulation possibilities are being explored by Andre Dejarlais and Tom Kollie of Oak Ridge National Laboratory. Present discussion is highly speculative, and no commercialization date is predicted. As PEP allows thinner walls, among its potential benefits are transportability of manufactured housing units and increase of the unit/volume shipping ratio. Cost is estimated at $1.50/sq ft, primarily for materials. Research and development of methods for incorporating PEP into building panels are required before the technology can be commercialized. Potential energy savings were below the threshold because this technology is applicable to new construction only.

S5. Switchable Glazings

Suntek, Inc., of Albuquerque, New Mexico, has developed and is marketing a clear plastic film which switches from transparent to reflective white at a preset temperature. Called CloudGel(TM), the film is a thermosensitive polymer which, in its activated state, realigns to block light. Change occurs over a 2-3°F range, set between 60-150°F, which is determined at the time of production and cannot be changed or disabled by the occupant. This allows for the use of large areas of south glazing to provide heating during the winter without the danger of overheating during the summer. Suntek has recently extended the CloudGel product life to 30 years. CloudGel is currently in production at a cost of $4/sq ft. CloudGel has also been incorporated into another product called WeatherPanel(TM). Licensed to KalWall Corp. of Manchester, New Hampshire, WeatherPanel is a pre-finished panel used as a building skin structural element (either wall or roof). The panel is 2 3/4 inches thick and can be manufactured in sizes up to 5' X 20'. It consists of outer panes of glass, plastic, or fiberglass; internal low-E baffles; and a coating of CloudGel on the inner pane. At the present cost of $20/sq ft, WeatherPanel is not cost-effective given California's mild climate.

S6. Aerogel

Aerogel is a silicon-based gel in which air substitutes for water within the structural lattice.

The substance has a small pore structure (~10nm) and is very light, stiff, brittle, and translucent. Convective and conductive heat transfer are very low and the addition of carbon black has been shown to greatly reduce radiative transfer. As a compact vacuum insulation in appliances or building skin structures, aerogel offers insulating values of R-20 per inch. It may also find application in an unsealed or clear-sealed form as glazing or skylight material with a rating of R-7 to R-20 per inch. Cost is projected at $1-2/sq ft, sensitive to material input prices (Martin, 1991). Projected market date is uncertain and varies with applications; the product is now used in functions unrelated to insulation. Due to its high cost, the use of aerogel as wall insulation is doubtful except where minimum thickness is important, such as in manufactured housing. Because aerogel use will be largely confined to specialized configurations in glazing, it does not achieve sufficient savings potential.

S7. Phase-Change Drywall

Phase-change drywall increases the heat capacity of conventional gypsum board by incorporating wax compounds into the gypsum. 10% wax (by weight) is added either by inclusion with silica beads during manufacture or by direct imbibing after manufacture (Sailor 1992). The wax undergoes a phase change at 68-75°F and absorbs sensible heat in the process. Potential savings of as high as 20% have been claimed, though the material is aimed more at comfort than conservation (Shipp 1992). Phase-change drywall might significantly reduce peak cooling loads. Potential material cost is estimated at $0.75 per 4x8 ft sheet (Olezewski 1992). At this time none of the major gypsum manufacturers has decided to move forward with commercialization of this technology. Potential energy savings were below the threshold because this technology is applicable to new construction only.

S8. Thermally resistive concrete

Pumice (a light-weight, air-impregnated volcanic rock) when mixed with Portland cement can be used to make a load-bearing and insulated wall suitable for one- to two-story construction. "Pumice-crete" has been used in New Mexico for about ten years, and is certified as a primary material in walls at least 12 inches thick. It is rated at 350-450 psi, and provides R-27 insulation at R-2.25/in. The material is popular as an proxy for adobe in residential construction as it is about $5/sq ft less expensive. It differs from typical concrete in density (45 lb/cu ft vs. 150 lb), construction considerations, and very high porosity (Magee 1992). Compared to standard wood construction, this technology is not cost-effective.

SPACE HEATING AND COOLING

H12. Hydraulic Compressor

The Hydraulic Refrigeration System (HRS) developed by Natural Energy Systems, Inc. uses a carrier fluid and hydraulic pressure for refrigerant compression (instead of a mechanical compressor). The HRS works by bubbling warm, gaseous refrigerant (low-side) into the top of a carrier fluid column. As the carrier descends, the gas is compressed and liquefied by hydrostatic pressure, transferring heat to the carrier. At the gravity separation chamber, the carrier is pumped back through a return cycle, during which heat is rejected via conventional exchange means (e.g., ground conduction, cooling tower, heat exchanger), while the refrigerant is passed through the evaporator. Overall system height is 100 feet (double- or triple-staging can be used to reduce this to 50 or 35 feet, respectively). In commercial installations the system could be placed in elevator shafts while for residential systems in-ground placement may be the only location feasible. Cooling capacities of from 1/2 to 20+ tons may be obtained, at EER's of 12-16. The HRS may also be operated as a heat pump (Duffy, 1990). A space-cooling unit, with an evaporator temperature of 45°F and using n-butane as the refrigerant and water as the carrier, is under development.

The HRS is claimed to outperform conventional air conditioning in two ways: It achieves 15% higher operating efficiency from the use of isothermal rather than adiabatic compression, and an anticipated 50% maintenance cost savings realized by the use of simple pumps instead of compressors. Estimated life is 20 years.

Disadvantages of the HRS include high initial cost, the flammability of HC refrigerants, and the system's height, which severely limits the number of suitable locations.

H13. Desiccant Cooling

Desiccant cooling enhances non-compressor cooling by reducing the humidity of incoming air through the use of chemical drying agents (desiccants). After absorbing moisture from indoor air, desiccants must be dried with heated outdoor air to regenerate their moisture-absorbing characteristic. A gas-fired heater may be used for rapid desiccant regeneration. With improved compounds and heat-exchanger designs, and by recycling process heat, EER's and costs of desiccant cooling cycles may become competitive with conventional air conditioning. A gas-fired desiccant cooler produced by Albers Air Conditioning Corporation is reportedly capable of achieving 5-20% energy savings vs. conventional cooling systems. Through dual-fuel (gas/electric) use, the unit may achieve cost savings of up to 50% (Albers 1992). In the design scenario, outside air at 94°F and 40% relative humidity (RH) is cooled to 54°/100%, to provide room conditions of 77°/60%. Operating range is for ambient conditions of 86°/80% to 107°/20%. Desiccant cooling is suitable both for commercial and for residential markets. The Albers cooler is slated for commercial markets in 1994. Anticipated cost is about $2000 for a 3-ton unit. Additional research and development, followed by demonstration projects, are the next appropriate steps to advance this technology. Because of the low latent outdoor latent load on most California buildings, desiccant cooling did not meet the savings threshold.

H14. Gas-Driven Heat Pump

A gas-driven heat pump is essentially a vapor compression heat pump powered by a gas-fired internal combustion engine. Engine cooling water is used as supplemental heat in heating mode and can provide DHW in cooling mode. Available in Japan since the early 1980s, gas-driven heat pumps are now reaching commercialization in the United States. York, in a project with GRI and Batelle, is now in Phase 2 of field testing a 3-ton residential unit with a planned commercialization date of January, 1994 (French 1992). Performance in California is estimated to be 1.3 gas COP for both heating and cooling with an installed cost of $6,500-6,800 (Labourn 1992). In addition to the high first cost, annual maintenance could be as high as $150. Future plans call for the development of a DHW option and a light commercial unit in the 5- to 8-ton range. The high cost and lack of cooling source energy savings, compared with an air conditioner meeting minimum Title 24 requirements, makes this technology non-cost-effective in California, but it should be cost-effective in areas with higher heating loads.

H15. Thermoelectric Cooling

An electric current applied across a circuit of two dissimilar metals will heat one junction and cool the other. Known as the Peltier effect, this phenomenon is commonly labeled thermoelectric cooling (TEC). As the maximum TEC efficiency is COP 1.4, TEC generally is not competitive with other cooling technologies unless efficiency is secondary to weight, size, and reliability. TEC is most commonly used for electronics and small-space refrigeration (less than 10 cubic feet), scientific apparatus, and recreational portable coolers. Very small sizes are possible, with a cooling chip measuring 0.16 in. x 0.16 in. x 0.11 in. available. The technology has no moving parts and is very rugged and reliable (Woolfolk 1992). Because the 1.4 COP is well below that of conventional vapor compression cooling, savings are negative.

H16. Occupancy Sensors

Occupancy sensors similar to those used for lighting control have recently been applied to HVAC systems, primarily in offices and hotels. Typically, sensors are set to shut off or set back thermostats in unoccupied areas, providing conditioning and ventilation savings. Integration with an energy management system can provide low cost control if direct digital control (DDC) is provided to zoned air delivery components. The sensors are most appropriate for buildings with 24-hour operating schedules and sporadic occupancy. In most buildings, standard setback controls with local override appear more cost-effective than occupancy sensors (Greenberg, 1992).

H17. Engine-Driven Air Conditioner

A 15-ton, gas-fired, internal-combustion air conditioning system has been developed by the American Gas Association Laboratories and the Gas Research Institute for use on low-rise commercial buildings. Electric consumption is restricted to ventilation fans. Condenser and radiator fans are driven by the engine. The system incorporates an advanced control package, providing optimum performance at full- or part-load operation. Four cooling modes utilizing a single compressor are possible by operating the engine at 2400, 1500, and 900 rpm full-load, or 900 rpm 50% load. Minor service is required every 2000-3000 hours, valve overhauls at 10,000 hours, and major overhauls at 20,000 hours. The principal benefit of the design appears to be energy cost savings. The system has a capacity of 15.8 tons, a gas COP of 0.91 and costs $900/ton (GRI 1992). The gas COP of this technology is not high enough to produce sufficient source energy savings when compared with an electric vapor compression system which meets minimum Title 24 requirements of 8.9 SEER (0.87 source COP).

H18. Advanced Data Visualization Software

Data visualization software for building energy management is an outgrowth of direct digital control (DDC) and real-time monitoring technologies incorporated in energy management and control systems (EMCS). Multi-dimensional graphical interfaces provide the potential to make voluminous data readily understandable and open to immediate evaluation through high-resolution, three-dimensional graphics using color, intensity, texture, blinking, and audio cues to highlight key data. Several volumetric graphs can be presented simultaneously and "sliced" along an axis for comparative analysis. Direct savings will vary widely with site and application. The software is most applicable to large buildings with complex HVAC systems and therefore did not achieve the specified savings threshold.

H19. Variable-Speed Fans in Non-Condensing Furnaces

Variable-speed fans are becoming increasingly common in condensing furnaces as manufacturers attempt to achieve higher efficiencies. Four major U.S. manufacturers currently sell gas furnaces with variable-speed blowers (Carrier, Heil, Trane, and Lenox). However, the high cost of these units makes them marginally economical in California's mild heating climate. Variable-speed technology is just beginning to be applied to non-condensing furnaces in the form of a dual-capacity unit (low and high burner rates and blower speeds) manufactured by Trane. Electronically commutated motors used with variable-speed blowers are 15% more efficient than typical motors. Advantages of variable-speed fans include lower blower energy consumption, reduced furnace cycling losses, and reduced duct leakage losses (although duct surface losses may be higher due to longer operating cycles). California heating fan energy use is not high enough for this technology to achieve the specified savings threshold.

H20. Triple-Effect Absorption Chiller

GRI and Trane have developed a prototype triple-effect absorption chiller with a gas COP of 1.5. Because it uses an additional generation stage to make better use of the high combustion temperature of natural gas, its efficiency increases to almost 50% more than existing double-effect units. Trane is expecting to have units on the market in two years (Dolan 1992). Cost savings from fuel switching and avoided peak electric charges can be substantial, but the efficiency of this unit does not provide source energy savings when compared with a central electric water chiller with a minimum Title 24 efficiency of 4.7 COP (1.57 source COP).

WATER HEATING

W4. PTV "Pop Cozy"

The "pop cozy," analogous to a tea cozy, is an insulated cover which can be fitted over the pressure temperature relief valve (PTV) of a hot water heater. The PTV is typically a metal valve installed at or near the top of the storage tank, with a drainpipe running down the tank to floor level or the outside. An uninsulated PTV loses 5-9 W, or 44-79 kWh/year, most of which could be saved by the cozy at a cost of approximately $.01/kWh (Bancroft et al., 1991). Building code issues may need to be resolved before the pop cozy can be commercialized. The technology offers excellent cost-effectiveness but cannot achieve the specified savings threshold.

DRIVEPOWER

D4. Smith Switched-Capacitor Motor

This design allows 120 hp, three-phase induction motors to be operated on a single-phase supply. It extends the range of three-phase motor--which are more efficient, more durable, and less expensive than single-phase motor--into areas where only single-phase power is available. The Smith motor is 12 percentage points more efficient than a single-phase motor at 1 hp, and 2 points more efficient at 20 hp (Smith, 1992). The inventor expects the cost to be comparable to and possibly less than conventional capacitor-run single-phase motors, but no data are available to verify this claim. It is applicable primarily to residential, small commercial, agricultural, and remote applications without three-phase service. Most residential appliance motors are too small to economically use this design, but central air conditioners, heavy shop tools, and pumps might be candidates. Air compressors, shop tools, and assembly equipment in small commercial and light industrial establishments, manure and water pumps on farms, and milk processing equipment at dairies are also potential applications. The Smith motor is applicable to new installations, not retrofits, particularly through original equipment manufacturers. A large motor manufacturer is testing prototypes of the design and commercialization is possible by 1995. Because it is limited to areas without three-phase service, this design does not have a large enough savings potential in the residential and commercial sectors of California to qualify for full analysis. Field demonstrations are needed.

D5. Design-E Motor Standard

The Design-E standard is a cooperative effort between the National Electrical Manufacturers Association (NEMA) Motor Rerate Task Force and industrial users to develop an improved voluntary standard for the efficiency of 1-500 horsepower polyphase squirrel-cage induction motors. The standard is expected to raise the efficiency of high-efficiency motors by 0.5 to 1 percentage point by reducing locked rotor current, but may lead to a decrease in power factor (Bartheld, 1992). The final draft standard is expected by fall 1993. The Design E standard is not likely to yield significant savings in California in 2010 because the proposed efficiency levels in the standard are already met or exceeded by a number of high-efficiency motors on the market today.

D6. Lower -Loss Motor Cores

Core losses represent about 20% of total energy losses in a motor, or about $300 million in losses in California per year. These losses can be reduced by using purer steel, different alloys, improved manufacturing and, potentially, amorphous metal cores. Typical motor laminations have core losses of 3 to 4 W/lb and cost $0.300.38/lb (Baldwin, 1988). Improved steel materials with higher purity and improved texture are available for about twice the price with core losses around 2 W/lb. Improved steel of this type is already used in some high-efficiency motors and adds about $100 to the cost of a 50 hp motor (Weiner, 1991). At an electricity rate of 10¢/kWh this will pay back in about 3,000 hours of operation. Amorphous steel alloys, which have been used successfully in transformers, have the potential to cut motor core losses to less than 10% of typical values, increasing the efficiency of a typical motor by nearly 2 percentage points. These materials are very expensive and brittle, however, so manufacturing and marketing challenges in motor applications remain significant hurdles. Rebates and standards that move the market toward more efficient motors will encourage manufacturers to incorporate moderately improved core steels in their designs; some of them are already doing so. Manufacturers are unlikely to adopt amorphous core materials on a wide scale, however, unless durability issues can be resolved and costs brought down. The more modest savings achievable in the residential and commercial sectors with improved steels are not enough to pass the savings threshold for more detailed analysis.

OFFICE EQUIPMENT

O4. Duplex Imaging Equipment

Approximately 20 Wh of electricity is used to produce a single sheet of virgin paper (Nordman, 1992). Thus, the majority of energy used for printing is in the production of the paper. The introduction of duplex printing and fax technologies affords significant opportunity for energy savings in the industrial sector (i.e. paper production) from reducing paper usage; there are no direct savings for equipment users from using duplex imaging equipment, and machines may consume more energy printing one double-sided image than two single-sided images. Hewlett-Packard introduced a printer in 1992 which can print on both sides of a sheet (Bell, 1992). While there are no fax machines which allow for automatic duplex imaging, inkjet facsimile machines and printers will accept used paper for reprinting on the unused side. While paper reuse is theoretically possible with plain-paper laser printers and faxes, there have been some problems with paper curling and misfeeding during reuse, and equipment manufacturers do not recommend this procedure to users.

O5. Fax/Printer Combination

Combination computer printer and fax machines afford the opportunity for energy consumption reduction. Several manufacturers have introduced combination units, including Hewlett-Packard, Canon, Relisys, and Okidata. The Okidata DOC-IT line, introduced in late 1992, features two machines with 8 page per minute laser printing, faxing (either from hardcopy or directly from a PC), scanning, and convenience copying. The machines idle at approximately 22W, thus drawing significantly less power than even a highly efficient system with an individual fax, copier, scanner, and printer. The units' list prices ranges from $4,000 to $5,000. However, all necessary circuitry to perform fax and copying functions reside on an expansion board for the PC or network server connected to the machine (Fax Buyer's Guide, 1992). Thus, simultaneous operation of at least one PC is required to perform even simple hardcopy faxing, thus increasing standby power consumption by at least two-fold (and much more with a non-power managed PC). Other combination machines, like the Canon CJ-10 color inkjet copier/printer/scanner/ fax, have greater built-in memory and function capabilities, but still require PC/modem connection for incoming fax reception. Additionally, other combination machines cost significantly more than the Okidata units, retailing at approximately $7000 plus $3000-5000 for the computer interface equipment. Even at the lower-end Okidata machine prices, the combination machines cost almost twice that of an individual inkjet printer, copier, and inkjet fax (Takahashi, 1992). Also, it is unlikely that the units will sell in large quantities and thereby account for significant energy savings, as most equipment buyers purchase components separately as needed for replacement. With advances in the integrated technology and subsequent cost decreases, these units may become cost effective.

O6. Flash and Pseudo-Static RAM Memory

Static RAM chips are faster and more efficient than standard dynamic RAM chips typically used in Pcs. The two chip types require equal amounts of energy when in use, but SRAM chips require almost no energy during stand-by, in contrast to the continually-drawing DRAM. Thus, energy savings of 70-80% of RAM usage can be expected (Newsham and Tiller, 1992). SRAM also has the benefit of requiring little refresh energy and thus allow the computer to be shut off with virtually no reboot period. Flash RAM chips similarly require no refresh energy and are extremely long-lasting and reliable. Both SRAM and flash RAM chips are small, high density devices that can store data typically stored in ROM, thus eliminating the need for hard disks. These chips can also be used in printers to retain soft fonts in printer memory when the printer is shut off. Flash RAM is approximately 10% higher in cost than DRAM, while SRAM is significantly higher in cost (Shepard et al., 1990). Energy savings from SRAM proliferation are limited, as RAM accounts for a small portion of total PC energy usage. However, use of this technology is expected to grow due to its non-energy benefits.

O7. Power Management Retrofits for Existing PCs

Power management of laptop computers is essential for minimizing battery drain. Power management features range from those which power down to 'sleep mode' after a set period of inactivity to those with several standby modes - rest, sleep, coma - with a corresponding range of lowered power consumption. All these programs allow the laptop to become active with a keystroke. The application of such programs to desktop Pcs would greatly reduce energy consumption, as active periods for typical desktop PCs range from only 20-30% of on-time. The Institute for Research in Construction of the National Research Council of Canada introduced the 'Smartbar' device in 1992. The device resembles a power strip and is connected to a host desktop PC. Software within the PC controls each socket to turn off the computer, peripherals, or other equipment after a specified period of inactivity on the keyboard. Power can be restored to the component by a keystroke (Newsham and Tiller, 1992). The unit is currently being sold by Sequence Electronics of Ontario (Reinhardt, 1992). There are several other similar devices commercially available in the U.S. and Canada with various features and costs ranging from $120 to $150 (E-Source, 1992).

The application of such programs to existing desktop PCs is limited by several factors. There are concerns that frequent cycling may reduce CRT life, but perhaps not enough to shorten life before the unit is technologically obsolete (Norford, 1992). The primary limiting factor, however, is the probability that power management software will be an integral component of new PCs by the end of 1993. If this occurs, the long-term savings from power management retrofits will be minimal given the 4-5 year useful life of the average PC.

O8. Improved PC Power Supply

Power supply for PCs presently operates at approximately 70% efficiency. Increasing this to 85% may be possible through power supply modifications. Manufacturers cite a cost of approximately $10 for the 15% improvement but state that they do not anticipate introducing this into their production processes in the near future (Khalifa, 1992). Additional benefits from improved power factor and lower total harmonic distortion are possible with improved power supplies, but these features may add further to costs. Savings potential for this measure did not meet the minimum 0.25% savings potential criteria.

COMMERCIAL COOKING

CC1. Advanced Electric Fryer

Improvements in deep-fat fryer insulation and temperature control, at an incremental cost of $200, may provide approximately 625 kWh annual savings (approximately $50 at $0.08/kWh). EPRI and Frymaster are jointly developing this product, which seeks to reduce conductive and standby losses of fryers and incorporates solid-state temperature control, optional demand limiting, and optional automatic temperature setback. Cost of saved energy is approximately 4¢, life is estimated to be 10 years, and market potential is approximately 258,000 U.S. electric fryers (California potential is unknown) (EPRI, 1992). This technology offers excellent cost-effectiveness, but due to limited energy use by electric fryers, it cannot achieve the specified savings threshold (EPRI 1992).

CC2. Pulse Combustion Griddle and Fryer

A high degree of temperature control (±10°F) and burn efficiency are possible using pulse combustion for griddle or fryer heat. Gas and air are mixed in a combustion chamber and ignited by electric spark. Fuel is regulated by check valves which close by burn pressure, then open during the exhaust stage. Once initiated, burn is maintained by residual heat and flame at about 35 cycles per second. Six burners on a typical griddle would provide controllable, constant heat; solid state controls would allow sections to be turned on or off with demand. This technology offers excellent cost-effectiveness, but due to limited energy use by gas cooking equipment, it cannot achieve the specified savings threshold.

CC3. Gas Double-Clamshell Griddle

A double-clamshell griddle utilizing a heat-transfer liquid circulating through upper and lower cooking surfaces offers 10-20% energy savings for hamburger cooking compared to two infrared griddles. The transfer liquid is heated in an adjacent gas-fired module. Temperature uniformity and cooking results are excellent, according to the Gas Research Institute, and a problem with heat-fluid leakages is said to be solved. Cost, preheat, and idle energy consumption data are not available. Due to limited gas used by griddles, overall savings for this technology are limited.

CC4. Improved Infrared Griddle

Southern California Gas Company and Wolf Range have developed an improved gas griddle which should be on the market in 1993. It achieves 85% efficiency, compared to 65% for a conventional IR griddle, by premixing air and gas. Anticipated incremental cost is zero. Wolf Range is currently conducting field tests. This technology offers excellent cost-effectiveness, but due to limited gas used by griddles, overall savings are limited.

CC5. Improved Gas Broiler

An improved gas broiler is being developed by Tecogen Inc., Burger King, and the Gas Research Institute (GRI). Project objectives are 50% energy savings, faster cooking times, reduced equipment size, and lower labor costs. The design incorporates vertical burger transport, reaches operating temperature in 30 seconds, and offers greater operator flexibility. This technology offers excellent cost-effectiveness, but due to limited energy use by gas cooking equipment, it cannot achieve the specified savings threshold.

CC6. Infrared (IR) Burner

Efficiencies of conventional cooktop gas burners are low (40-45%) due to combustion air-draw requirements. The IR burner uses a blower to feed a gas-air mix to a perforated ceramic-tile burner where combustion occurs. Both radiative and convective heat transfer are enhanced by this design due to the concentration of heat in the tile and air movement through it. Incidental benefits are cleaner combustion and reduced waste heat (cooler kitchen temperature). Energy savings are up to 50% at high power. The design allows 3:1 power adjustment range. Wolf Range is completing field tests and expects to have a product on the market in the first quarter of 1993. Incremental price for a two-burner range is $950, which may fall to $500 after discounts. This technology offers excellent cost-effectiveness, but due to limited energy use by gas cooking equipment, it cannot achieve the specified savings threshold.

CC7. Infrared Burner in Convection Oven

A high-efficiency convection oven, designed by the American Gas Association Laboratories (AGAL) with Gas Research Institute support, incorporates infrared burners and other enhancements to achieve 45-55% efficiency improvements over conventional ovens, with comparable cooking time reductions. The design is being applied to the Snorkel (tm) convection range oven (produced by Vulcan-Hart Corporation) which has a heat input of 60,000 Btu/hr and reaches 400°F in 15 minutes. Besides IR burners, the oven incorporates a motor/blower for pre-burn gas-air mixing, internal baffling, and oven and combustion chamber sealing. Cost is $4,430; life is 10 years; maintenance savings are estimated to be $200 annually. GRI computes payback period as three years. This technology offers excellent cost-effectiveness, but it cannot achieve the specified savings threshold.

CC8. Smart Electric Griddle

A self-regulating electric griddle is being developed by Metcal of Menlo Park, California, using a principle called "smart heat," a combination of controls and metal alloy that keeps the griddle idling at a designated temperature. This temperature is maintained within ±5 degrees Fahrenheit regardless of the load imposed on it. By using electricity only where and when needed, griddle efficiencies of 65-85% can be obtained. The griddle will be released in January, 1993 with a cost premium of 20-25% over conventional griddles (Scott 1992). Due to the small amount of energy used by commercial cooking, this technology does not meet the minimum savings criteria.

MISCELLANEOUS

M1. Ultrasonic Dishwashing

This technology substitutes sound waves for water spray in the prerinse and potentially in part of the wash cycle of a commercial dishwasher, reducing hot water use by a projected 25-50%. Instead of spraying the dishes to dislodge large food particles, the dishes are immersed in a tank of water and bombarded with high frequency sound waves that create tiny vapor bubbles which are very effective at removing food particles from even the most remote crevices. The water in the tank is filtered and most is reused for the next cycle. The manufacturer claims that the technology will increase the cost of a commercial dishwasher by $1,000$2,000 (Evans, 1992), but one analyst who asked to remain anonymous believes the cost premium will be several times larger. Two commercial prototypes are being installed and monitored by Southern California

Edison, with early test results expected in 1993. If it proves to be cost-effective, ultrasonic dish washing can reduce water consumption and waste water production, as well as reducing energy use. The technology may have broader applicability, in cleaning industrial and pharmaceutical tanks, tanker trucks, and other process vessels. If test results are positive, product development and manufacturing support will be needed, along with additional demonstration projects. Cost-effectiveness and overall energy savings are still highly uncertain. Even if the developer's claims are borne out, due to the limited amount of energy used for commercial dishwashing, the device does not save enough energy to meet this study's threshold for more detailed treatment.

Chapter 4

DISCUSSION AND CONCLUSIONS

SUMMARY OF FINDINGS

The preceding chapters discuss 102 emerging technologies, including 53 medium/high priority technologies and 49 lower priority technologies. Taken together, these technologies have enormous potential to reduce energy use in California. When the energy that could be saved in 2010 by the 52 medium/high priority technologies is summed, assuming installation in all feasible applications, the total is approximately 50% of energy use in California's buildings. This figure includes extensive double-counting of savings from similar or overlapping technologies. If only measures which do not overlap are counted, the technical potential for savings is still in excess of 25%. Even if many of these technologies never make it to market, the savings potential is still substantial. This indicates that opportunities for achieving considerable savings from DSM programs will continue through 2010 and beyond.

Of the available savings, savings opportunities appear to be most pronounced in three end uses -- lighting, appliances, and HVAC. However, potential savings are also substantial in other end-uses including water heating, office equipment, commercial laundering, and motors.

Savings and cost of saved energy for the individual technologies examined are summarized in Table 4-1 and Figures 4-1 and 4-2.

HIGH PRIORITY TECHNOLOGIES

Given the many technologies discussed in this report, it is useful to identify the technologies with the largest potential for cost-effective savings. These technologies were selected based on two criteria:

- Energy savings ratings of 1.0% or more, <u>and</u>

- Levelized cost of less than $0.06/kWh or $0.40/therm (these values are based on the approximate long-run avoided cost of California utilities).

Technologies which pass these criteria are summarized in Table 4-2. Of course, other factors need to be examined before decisions are made about which technologies to promote (examples of these factors are likely market acceptance and the amount of effort and time that will be required to make a technology succeed in the market). Still, prime targets for action are likely to come from this list. The next steps recommended to advance these technologies were discussed in Chapter 2. For technologies making the high priority list, these next steps are summarized in Table 4-3.

Table 4-1. Medium/High Priority Emerging Technologies.

	Savings Potential Rating (% of 2010 CA R&C Energy Use)	Cost of Saved Energy $/kWh	Cost of Saved Energy $/therm
Appliances			
1. Golden Carrot refrigerator	1.6	0.03	NA
2. 200-300 kWh refrigerator/freezer	0.6	0.04	NA
3. Advanced freezer	0.3	0.06	NA
4. Horizontal axis clothes washer	1.9	-0.09	-1.9
5. High spin speed clothes washer	1.1	0.03	0.8
6. Automatic clothes washer controls	0.6	0.06	NA
7. Bubble-action washing machine	0.8	0.06	NA
8. Microwave clothes dryer	0.6	0.09	NA
9. Heat pump clothes dryer	1.3	0.05	NA
10. Low energy and water use dishwashers	0.9	0.02	0.3
11. Low-temperature dishwashing detergent	0.4	0.00	0.1
12. Low powered color TV	0.3	0.03	NA
Lighting			
1. General service halogen IR	1.2	0.01	NA
2. Coated filament incandescent	3.6	0.01	NA
3. Hafnium carbide single crystal filaments	2.6	0.02	NA
4. 100W Equivalent screw-in fluorescent	1.0	0.02	NA
5. Compact fluorescent floor & table lamps	0.5	0.03	NA
6. Dimmable compact fluorescents	0.4	0.01	NA
7. Fluorescent surface wave lamp	1.3	0.02	NA
8. DC lighting system	0.5	0.01	NA
9. Scotopic lamp	0.5	0.03	NA
10. Advanced reflector design	0.6	0.04	NA
11. Thermal bridging for fluorescent fixtures	0.5	0.01	NA
12. Lower cost dimmable ballasts	0.7	0.02	NA
13. Integrated fixtures/controls	0.3	0.04	NA
14. Architectural daylighting devices	0.3	0.04	NA
15. Electrodeless HID	0.3	-0.01	NA
Building Shell			
1. High R Glazing	0.5	NA	0.6
Space Heating and Cooling			
1. High efficiency packaged air conditioners	1.1	0.05	NA
2. Ground source heat pump	0.5	0.07	NA
3. Cool ceiling with displacement ventilation	0.3	0.12	NA
4. Cool storage roof	1.7	0.01	NA
5. GAX absorption heat pump	1.1	0.08	NA
6. Indirect/direct evaporative cooling	1.0	0.06	NA
7. Adsorption cooling	0.7	0.04	NA
8. Improved ducts and fittings	0.8	NA	0
9. Internal access duct sealants	1.2	NA	0
10. Zeotropic refrigerants	1.1	0.06	NA
11. Electrohydrodynamic heat transfer enhancement	1.8	0.06	NA
Water Heating			
1. Pilotless Instantaneous DHW	1.8	NA	0.4
2. Combination Refrigerator/Water Heater	1.2	NA	0.3
3. Ultrasonic Faucet Control	0.5	NA	0.9
Commercial Refrigeration			
1. High R case doors	0.5	0.03	NA
2. Very low head pressure	0.3	0	NA
3. Supermarket system integration	0.5	0.02	NA
Motors			
1. Green Plug motor controller	0.4	0.09	NA
2. Switched reluctance drives	1.5	0.05	NA
3. Five phase motors	1.5	0.05	NA
Office Equipment			
1a. Low-energy desktop PC (w/active matrix)	1.0	0-0.12	NA
1b. Low-energy desktop PC (without active matrix)	0.7	0	NA
2. Improved inkjet and bubblejet printers/faxes	0.7	negative	NA
3. Improved cold-fusing/low energy fusing copiers/printers/faxes	0.7	0	NA
Commercial Laundering			
1. Ozonated commercial laundering	1.9	NA	NA

Figure 4-1. Electricity Saving Measures.

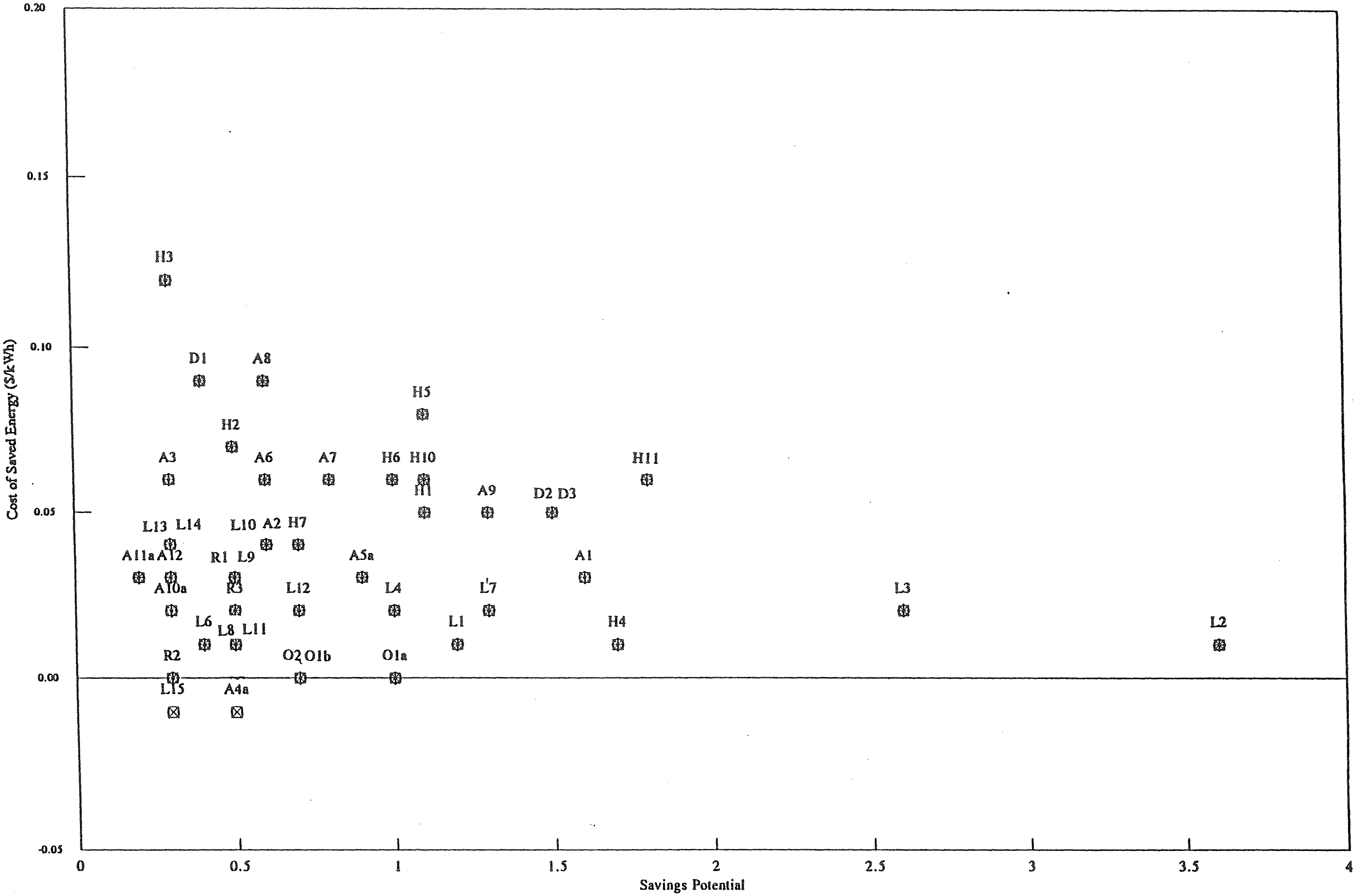

Figure 4-2. Gas Saving Measures.

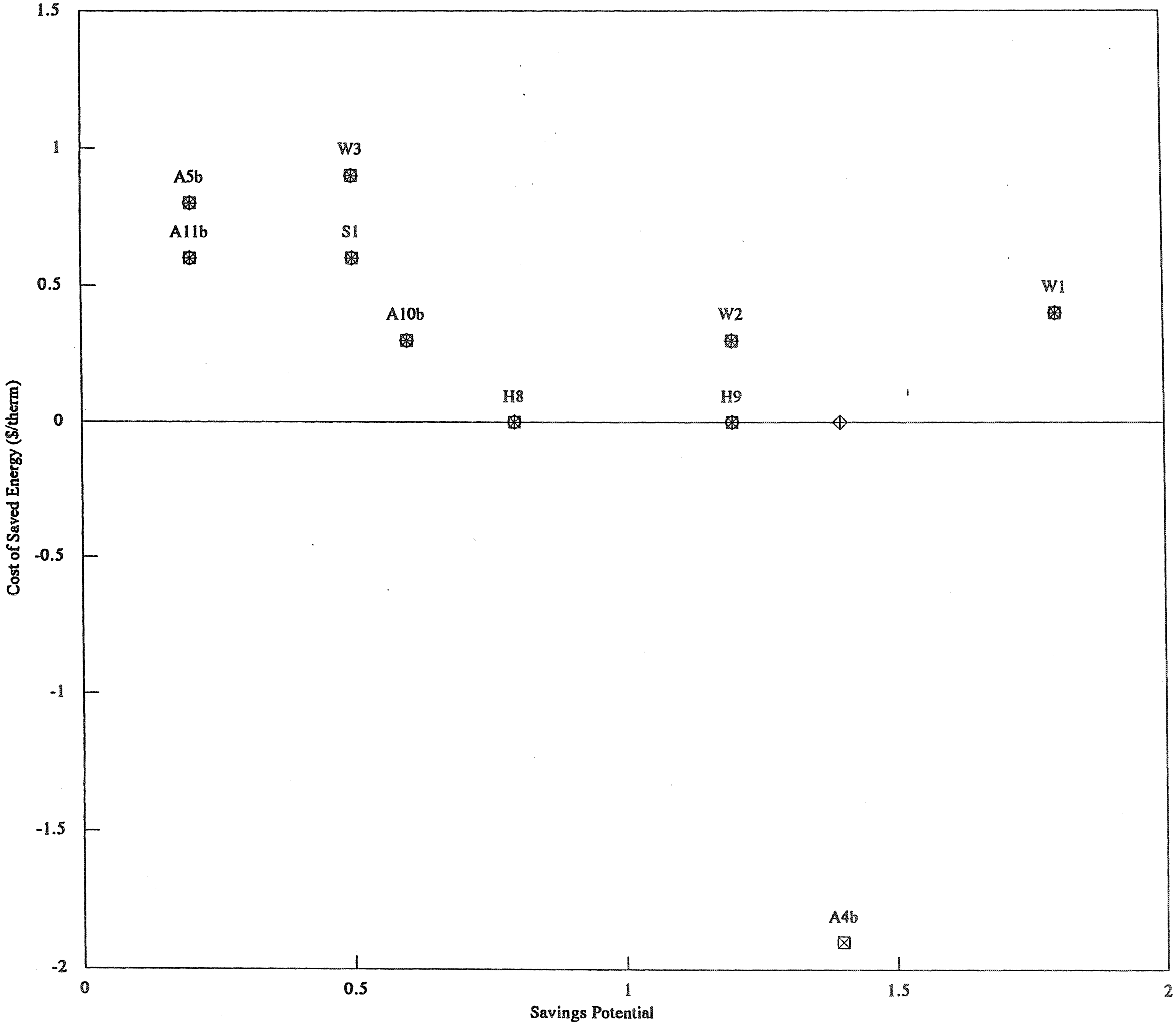

Table 4-2. High Priority Emerging Technologies.

	Savings Potential Rating (% of 2010 CA R&C Energy Use)	Cost of Saved Energy $/kWh	Cost of Saved Energy $/therm	Next Steps
Appliances				
1. Golden Carrot R/F	1.6%	0.03	NA	Rebates
2. Horiz. axis clothes washer	1.9	(0.09)	(1.9)	Golden Carrot
3. High spin speed clothes washer	1.1	0.03	0.8	Golden Carrot
4. Heat pump clothes dryer	1.3	0.05	NA	Tests & demos
Lighting				
5. Gen. service halogen IR lamp	1.2	0.01	NA	R&D
6. Coated filament incandescent	3.6	0.01	NA	R&D
7. Hafnium carbide filaments	2.6	0.02	NA	R&D
8. 100 W equiv.screw-in fluor.	1.0	0.02	NA	Rebates
9. Fluor. surface wave lamp	1.3	0.02	NA	R&D
HVAC				
10. High eff. packaged A/C	1.1	0.05	NA	Golden Carrot
11. Cool storage roof	1.7	0.01	NA	Tests & demos
12. Indirect/direct evap. cooling	1.0	0.06	NA	Tests & demos
13. Internal access duct sealants	1.2	NA	0.0	Tests & demos
14. Zeotropic refrigerants	1.1	0.06	NA	R&D
15. Elec. heat transfer	1.8	0.06	NA	R&D
Water Heating				
16. Pilotless instant. DHW	1.8	NA	0.4	Rebates
17. Comb. refr./water heater	1.2	NA	0.3	R&D
Drivepower				
18. Switched reluctance drives	1.5	0.05	NA	Tests & demos
19. Five-phase motors	1.5	0.05	NA	Tests & demos
Office Equipment				
20. Low energy desktop PC	1.0	0-0.12	NA	Education
Other				
21. Ozonated laundering	1.9	NA	NA	Tests & demos

Table 4-3. Next Steps to Advance High Priority Emerging Technologies.

* Research and development
    - general service halogen IR lamp
    - coated filament incandescent
    - hafnium carbide filaments
    - fluorescent surface wave lamp
    - zeotropic refrigerants
    - electrohydrodynamic heat transfer enhancement
    - combined refrigerator/water heater

* Tests and demonstrations
    - heat pump clothes dryer
    - cool storage roof
    - internal access duct sealants
    - indirect/direct evaporative cooling
    - switched reluctance drives
    - five phase motors
    - ozonated laundering

* Education and promotion
    - low energy desktop PC

* Utility rebates
    - Golden Carrot refrigerator/freezer
    - 100 W equivalent fluorescent
    - pilotless instantaneous DHW

* Golden carrot programs (in many cases these programs may be similar to utility rebate programs)
    - horizontal axis clothes washer
    - high spin speed clothes washer
    - high efficiency packaged air-conditioner

RECOMMENDATIONS

Based on the research described in this report, five actions are recommended:

1. Begin pursuing the next steps to advance the high priority technologies, as summarized in Tables 4-2 and 4-3.

2. Track and evaluate the success of efforts to advance these technologies, so that approaches for advancing emerging technologies can continue to be refined.

3. Review efforts to promote existing technologies, to make sure that promising existing technologies are receiving adequate attention. Among the existing technologies that may not be receiving adequate attention are the technologies listed in Appendix A.

4. Conduct an emerging technologies assessment for the industrial and agricultural sectors. While some of the measures covered in this study can be used in the industrial and agricultural sectors, many new technologies are being developed that are suited only for the industrial and agricultural sectors. Given the large amounts of energy that are used in the industrial and agricultural sectors, a study examining emerging technologies for these sectors is likely to be rewarding. A major focus of this study should be on process energy use.

5. Reexamine emerging technologies for the residential and commercial sectors in approximately three years. New technologies are in a constant state of flux. The status of many of the technologies listed here may change over this period of time and up-to-date information on costs, savings, and current status should be collected. Also, new technologies are likely to be developed which merit further exploration, including ideas listed in Appendix B and new ideas not listed in this report.

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Appendix A

EXISTING BUT UNDERUTILIZED TECHNOLOGIES

APPLIANCES

A1. Induction cooktop.
A2. Cold-water laundry detergents.
A3. Halogen cooktops.

LIGHTING

L1. Polarizing lenses.
L2. Skylights and clerestories for daylighting.
L3. PV for remote lighting (e.g. PV walkway lights).
L4. Task tuning controls.

SHELL

S1. Structural foam panels.
S2. Rammed earth.
S3. Light-colored roofs.
S4. Insulated forms.
S5. Low-E/spectrally selective retrofit window films.

SPACE HEATING AND COOLING

H1. Three function integrated heat pump.
H2. Heat pipe enhanced air conditioning.
H3. Integrated residential thermal storage.
H4. Air-to-air enthalpy recovery/exchange systems.
H5. Solar absorption air conditioning.
H6. Zoned and VAV residential systems.
H7. Dual fuel heat pumps.
H8. Ducts in conditioned space.
H9. Ductless thermal distribution systems.
H10. Larger gauge electrical wire.
H11. Down-sized pool pumps with large piping.
H12. PV pool pumps.
H13. Dual path air conditioning systems.
H14. Larger heat exchangers.
H15. Two-speed air-conditioners and heat pumps (SEER ~15).
H16. Variable-speed air-conditioners and heat pumps (SEER ~16).
H17. Commercial desiccant-based gas-fired A/C systems.
H18. Integrated chillers with heat recovery.
H19. Heat recovery heat pumps for commercial applications.

H20. Variable pressure control for VAV systems.
H21. Mini-split A/C.
H22. Evaporative condensing for DX systems.
H23. Ceramic thermal storage.
H24. Low face velocity/high coolant velocity cooling coil.
H25. Open-protocol energy management systems.
H26. Cold air distribution.
H27. Transpired un-glazed solar collector.

DOMESTIC HOT WATER

W1. 90% efficient and above water heaters (Polaris, AERCO, etc.).
W2. Parallel piping.
W3. Alcohol pumped solar water heater (Copper Cricket).
W4. Computer controlled DHW temperature reset.
W5. Tempering valve.
W6. Showerheads of 2.0 gpm and lower.
W7. Heat pump water heaters.

DRIVEPOWER

D1. Permanent magnet motors
D2. Synchronous belts and flat belts
D3. Premium lubricants
D4. Two-speed motors and pony motors
D5. Rewinding using mechanical stripping

COMMERCIAL REFRIGERATION

R1. Liquid pressure amplifier.
R2. External liquid suction heat exchangers
R3. Low head pressure with evaporative condensers
R4. Flash chilling by immersion.

OFFICE EQUIPMENT

O1. PC's as substitutes for scientific work stations.
O2. Networked PC's and work stations as substitutes for mini- and mainframe computers.
O3. Fax boards in PC's, reducing need for fax machines.
O4. Fax machines with overnight memory.
O5. Duplexing copiers (copy of both sides of paper).

COMMERCIAL COOKING

C1. Split vat fryers.
C2. Gas infrared burners, griddle, and fryer.
C3. Convection ovens.
C4. Two surface griddle.
C5. Instant burger.
C6. Power burner cooktop.

MISCELLANEOUS

M1. Commercial heat pump clothes dryer
M2. Temperature setback in commercial laundering

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Appendix B

ADVANCED IDEAS

(Ideas not presently being worked on or unlikely to be commercialized in next ten years)

1. Integrated window/wall unit
2. Soil cooling
3. Night roof cooled thermal storage
4. Differential temperature sensor for window ventilation
5. Weather forecast control of thermal mass venting
6. Dollar meters
7. Real time demand meters
8. EMCS with smarter diagnostics, metering, and O&M capabilities
9. Heated furniture
10. Variable flow pool filter with automatic turbidity control
11. Water main source heat pump
12. High R-value easy-to use duct retrofit insulation
13. Seasonal storage
14. Remote evaporative condensers for self contained retail cases
15. Electrical energy storage (chemical, mechanical, etc.)
16. Recuperative condenser
17. Hybrid vapor-compression heat and humidity pump
18. Evaporative condensing for DX systems
19. Improved heat exchangers for chillers
20. Free piston sterling engine as a prime mover for refrigeration
21. Integration of water loop heat pumps with thermal storage
22. Hot gas defrost for heat pumps
23. Automatic cooking controls
24. Insulating hot water tank in commercial dishwashers
25. Solid state lighting
26. Imaging control system for lighting
27. Advanced phosphors
28. Two-photon phosphor for fluorescent lamps
29. Regenerative elevators