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EMERGING ENERGY-EFFICIENT INDUSTRIAL TECHNOLOGIES

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EXECUTIVE SUMMARY

U.S. industry consumes approximately 37 percent of the nation's energy to produce 24 percent of the nation's GDP. Increasingly, industry is confronted with the challenge of moving toward a cleaner, more sustainable path of production and consumption, while increasing global competitiveness. Technology will be essential for meeting these challenges. At some point, businesses are faced with investment in new capital stock. At this decision point, new and emerging technologies compete for capital investment alongside more established or mature technologies. Understanding the dynamics of the decision-making process is important to perceive what drives technology change and the overall effect on industrial energy use.

The assessment of emerging energy-efficient industrial technologies can be useful for:

- identifying R&D projects;
- identifying potential technologies for market transformation activities;
- providing common information on technologies to a broad audience of policy-makers; and
- offering new insights into technology development and energy efficiency potentials.

With the support of PG&E Co., NYSERDA, DOE, EPA, NEEA, and the Iowa Energy Center, staff from LBNL and ACEEE produced this assessment of emerging energy-efficient industrial technologies. The goal was to collect information on a broad array of potentially significant emerging energy-efficient industrial technologies and carefully characterize a sub-group of approximately 50 key technologies. Our use of the term "emerging" denotes technologies that are both pre-commercial but near commercialization, and technologies that have already entered the market but have less than 5 percent of current market share. We also have chosen technologies that are energy-efficient (i.e., use less energy than existing technologies and practices to produce the same product), and may have additional "non-energy benefits." These benefits are as important (if not more important in many cases) in influencing the decision on whether to adopt an emerging technology.

DEFINITION OF "EMERGING" TECHNOLOGY

The technologies were characterized with respect to energy efficiency, economics, and environmental performance. The results demonstrate that the United States is not running out of technologies to improve energy efficiency and economic and environmental performance, and will not run out in the future. We show that many of the technologies have important non-energy benefits, ranging from reduced environmental impact to improved productivity and worker safety, and reduced capital costs.

Methodology

The assessment began with the identification of approximately 175 emerging energy-efficient industrial technologies through a review of the literature, international R&D programs, databases, and studies. The review was not limited to U.S. experiences, but rather we aimed to produce an inventory of international technology developments. We devised an initial screening process to select the most attractive technologies that had: (1) high potential energy savings; (2) lower comparative first costs relative to existing technologies; and (3) other significant benefits. While some technologies scored high on all of these characteristics, most had a mixed score. We formalized this approach in a very simple rating system. Based on the literature review and the application of initial screening criteria, we identified and developed profiles for 54 technologies. The technologies ranged from highly specific ones that can be applied in a single industry to more broadly crosscutting ones that can be used in many industrial sectors.

Each of the selected technologies has been assessed with respect to energy efficiency characteristics, likely energy savings by 2015, economics, and environmental performance, as well as what's needed to further the development or implementation of the technology. The technology characterization includes a one to two-page description and a one-page table summarizing the results for the technology.

Summary of Results

Table ES-1 provides an overview of the 54 emerging energy-efficient industrial technologies. We evaluated energy savings in two ways. The third column of Table ES-1 (Total Energy Savings) shows the amount of total manufacturing energy that the technology is likely to save in 2015 in a business-as-usual scenario. The fourth column (Sector Savings) reflects the savings relative to expected energy use in the particular sector. We believe that both metrics are useful in evaluating the relative savings potential of various technologies.

Economic evaluation of the technology is identified in the summary table by simple payback period, defined as the initial investment costs divided by the value of energy savings less any changes in operations and maintenance costs. We chose this measure since it is frequently used as a shorthand evaluation metric among industrial energy managers. Payback times for the technologies range from the immediate to 20 years or more. Of the 54 technologies profiled, 31 have estimated paybacks of 3 years or less, with six paying back immediately

Energy savings are most often not the determining factor in the decision to develop or invest in an emerging technology. Over two-thirds of technologies not only save energy but yield non-energy benefits. We separated these non-energy benefits into environmental and other categories. We assessed how important the environmental benefits are to the technology adoption decision and listed the nature of the other benefit(s). We include an assessment of the importance of these non-energy benefits.

Technologies do not seamlessly enter existing markets immediately after development. The acceptance of emerging technologies is often a slow process that entails active research and development, prototype development, market demonstration, and other activities. In Table ES-1 we summarize the recommendations for the primary activities that could be undertaken to increase the technologies' rate of uptake. Over half of these technologies have already been developed to prototype stage or are already commercial but require further demonstration and dissemination.

Each technology is at a different point in the development or commercialization process. Some technologies still need further R&D to address cost or performance issues, some are ready for demonstration, and others have already proven themselves in the field and the market needs to be informed of the benefits and market channels needed to develop skills to deliver the technology. Our outlining of recommended actions in Table ES-1 is not an endorsement of any particular technology. Technology purchasers and users will ultimately decide regarding future development. However, the actions specified are intended to help identify whether a technology is both technically and economically viable and whether it is robust enough to accommodate the stringent product quality demands in various manufacturing establishments.

Seventeen emerging technologies could benefit from additional R&D. We suggest further R&D for several primary metal technologies, and several cross-cutting motor and utility technologies. In addition to private research funds, several of the identified technologies have received some R&D support from DOE or other public entities, including federal and state agencies.

There are also a large number of technologies that already have made some headway into the marketplace or are at the prototype testing stage, and therefore are candidates for demonstration for potential customers to gain comfort with the technology. While we recommend further demonstration and dissemination of these technologies, it was often difficult to understand what is limiting their uptake without more comprehensive investigation of market issues. Some of the technologies in this category are common in European countries or Japan but have not yet penetrated the U.S. market. Others are being newly developed in the United States and face challenges in reducing the risks perceived by potential purchasers. Two technologies, motor system optimization and pump efficiency improvement, are opportunities for training programs similar to those developed by DOE for the compressed air system management. For advanced industrial CHP turbine systems, the major recommended activity is removal of policy barriers. For other technologies, their unique markets will dictate the form of the educational and promotional activities. We urge the reader to follow up on any details in the specific technology profiles provided in Section VI of this report .

TYPES OF SUPPORT NEEDED TO MOVE EMERGING TECHNOLOGIES FURTHER INTO MARKETPLACE

Table ES-1. Summary of Profiled Emerging Energy-Efficient Industrial Technologies

Technology	Sector	Total[1] Energy Savings	Sector[2] Savings	Simple Payback	Environ. Benefits	Other[3] Benefits	Suggested Next Steps	Likelihood of Success
Advanced forming	Aluminum	Medium	Medium	Immediate	None	P	R&D	High
Efficient cell retrofit designs	Aluminum	High	High	2.7	Somewhat	P	Demo	High
Improved recycling technologies	Aluminum	Medium	Medium	4.5	Significant	P	Demo	Medium
Inert anodes/wetted cathodes	Aluminum	High	High	4.0	Significant	P, Q	R&D	Medium
Roller kiln	Ceramics	Medium	High	1.9	Significant	P	Demo	Medium
Clean fractionation—cellulose pulp	Chemicals	Low	Low	1.9	Significant	P, O	Demo	Medium
Gas membrane technologies—chem.	Chemicals	Low	Low	10.2	Significant	Q, O	Dissem.	High
Heat recovery technologies—chem.	Chemicals	Medium	Medium	2.4	None	P, O	Dissem., Demo	Medium
Levulinic acid from biomass	Chemicals	Low	Low	1.5	Significant	P, O	Demo	High
Liquid membrane technologies—chem.	Chemicals	Low	Low	11.2	Significant	O	Dissem.	Medium
New catalysts	Chemicals	Medium	Medium	7.9	Somewhat		R&D	Medium
Autothermal reforming—ammonia	Chemicals	High	High	3.7	Significant	P	Dissem	Medium
Plastics recovery	Plastics	Medium	Medium	2.8	Compelling	P	Demo	High
Continuous melt silicon crystal growth	Electronics	Medium	High	Immediate	Somewhat	P, Q	R&D	High
Electron beam sterilization	Food	High	High	19.2	None	P, Q	R&D	Low
Heat recovery—low temperature	Food	Medium	Medium	4.8	None	P, Q	Dissem.	Low
Membrane technology—food	Food	High	High	2.2	Somewhat	P, Q	Dissem., R&D	Medium
Cooling and storage	Food	Medium	Medium	2.6	Somewhat	O	Dissem., Demo	Medium
100% recycled glass cullet	Glass	Medium	High	2.0	Significant		Demo	High
Hi-tech facilities HVAC	Crosscutting	Medium	High	4.0	None	P	Dissem.	Medium
Advanced lighting technologies	Crosscutting	High	High	1.3	None	P, Q, O	Dissem., Demo	High
Advanced lighting design	Crosscutting	High	High	3.0	None	P, Q, O	Dissem., Demo	Medium
Variable wall mining machine	Mining	Low	Low	10.6	None	P, S	Demo	Low
Advance ASD designs	Crosscutting	High	Medium	1.1	None	P, Q	R&D	High
Advanced compressor controls	Crosscutting	Medium	Low	0.0	None	P, Q	Dissem.	Medium
Compressed air system management	Crosscutting	High	High	0.4	None	P, Q	Dissem.	Medium
Motor diagnostics	Crosscutting	Low	Low	Immediate	None	P, Q	Dissem., Demo	High
Motor system optimization	Crosscutting	High	High	1.5	Somewhat	P, Q	Dissem., Train	Medium
Pump efficiency improvement	Crosscutting	High	High	3.0	None	P, Q	Dissem., Train	Medium
Switched reluctance motor	Crosscutting	Medium	Low	7.4	None	P, Q	R&D	Medium
Advanced lubricants	Crosscutting	Medium	Medium	0.1	Significant	P, Q	Dissem.	Medium
Anaerobic waste water treatment	Crosscutting	Medium	Low	0.8	Significant	O	Dissem., Demo	High
High-efficiency/low NO_x burners	Crosscutting	High	Low	3.1	Significant	P	Dissem., Demo	Medium
Membrane technology wastewater	Crosscutting	High	Medium	4.7	Somewhat	P	Dissem., R&D	High
Process integration (pinch)	Crosscutting	High	Low	2.3	Somewhat	P	Dissem.	Medium
Sensors and controls	Crosscutting	High	Medium	2.0	Somewhat	P, Q	Dissem., R&D, demo	High

Table ES-1. Summary of Profiled Emerging Energy-Efficient Industrial Technologies (continued)

Technology	Sector	Total[1] Energy Savings	Sector[2] Savings	Simple Payback	Environ. Benefits	Other[3] Benefits	Suggested Next Steps	Likelihood of Success
Black liquor gasification	Pulp & paper	High	High	1.5	Somewhat	P, S	Demo	High
Condebelt drying	Pulp & paper	High	Medium	65.2	None	P, Q	Demo	Low
Direct electrolytic causticizing	Pulp & paper	Low	Low	N/A	Somewhat	P, Q	R&D	Medium
Dry sheet forming	Pulp & paper	Medium	Medium	48.3	Somewhat	Q	R&D, demo	High
Heat recovery—paper	Pulp & paper	High	Medium	3.9	Somewhat	P, S	Demo	Medium
High consistency forming	Pulp & paper	Medium	Medium	Immediate	Somewhat	P, Q	Demo	Medium
Impulse drying	Pulp & paper	High	Medium	20.3	None	P, Q	Demo	Medium
Biodesulfurization	Pet. Refining	Medium	Medium	1.8	None	Q	R&D, demo	High
Fouling minimization	Pet. Refining	High	High	N/A	None	P	R&D	Low
BOF gas and sensible heat recovery	Iron & steel	Medium	Medium	14.7	Significant	P	Dissem.	Low
Near net shape casting/strip casting	Iron & steel	High	High	Immediate	Somewhat	P, Q	R&D	High
New EAF furnace processes	Iron & steel	High	High	0.3	Somewhat	P	Field test	High
Oxy-fuel combustion in reheat furnace	Iron & steel	High	Medium	1.2	Significant	P	Field test	High
Smelting reduction processes	Iron & steel	High	High	Immediate	Significant	P	Demo	Medium
Ultrasonic dying	Textile	Medium	Medium	0.3	Compelling	P, Q	Demo	Medium
Advanced CHP turbine systems	Crosscutting	High	High	6.9	Significant	P, Q	Policies	High
Advanced reciprocating engines	Crosscutting	High	High	8.3	Limited	P, Q, O	R&D, demo	Medium
Fuel cells	Crosscutting	High	High	58.6	Significant	P, Q	Demo	Medium
Microturbines	Crosscutting	High	Medium	Never	Somewhat	P, Q, O	R&D, demo	Medium

Notes: 1. "High" could save more than 0.1% of manufacturing energy use by 2015, "medium" saves 0.01 to 0.1%, and "low" saves less than 0.01%.
2. "High" could save more than 1% of sector energy use by 2015, "medium" saves 0.1 to 1%, and "low" saves less than 0.1%.
3. "P"=productivity, "Q"=quality, "S"=safety, and "O"=other.

We assess the technology's likelihood of success in the marketplace. While our study evaluates each technology in relation to a given reference technology, the reality of the market is that technologies compete for market share. We made a judgement (based on the energy savings, cost-effectiveness, importance of non-energy benefits, market conditions, data reliability, and potential competing technologies) as to the likelihood that the technology would succeed in the marketplace.

From a national energy policy perspective, it is important to understand which technologies have both a high likelyhood of success and a high energy-savings. While various audiences may be interested in sector-specific or regional-specific technologies, the technologies listed in Table ES-2 are intended to provide guidance to those interested in the impact of energy-saving technologies on a more national level. This table also identifies the recommended next steps appropriate for each technology.

Table ES-2. Technologies with High Energy Savings and a High Likelihood of Success

Technology	Code	Total Energy Savings	Likelihood of Success	Recommended Next Steps
Efficient cell retrofit designs	Alum-2	High	High	Demo
Advanced lighting technologies	Lighting-1	High	High	Dissem., demo
Advance ASD designs	Motorsys-1	High	High	R&D
Membrane technology wastewater	Other-3	High	High	Dissem., R&D
Sensors and controls	Other-5	High	High	R&D, demo, dissem.
Black liquor gasification	Paper-1	High	High	Demo
Near net shape casting/strip casting	Steel-2	High	High	R&D
New EAF furnace processes	Steel-3	High	High	Field test
Oxy-fuel combustion in reheat furnace	Steel-4	High	High	Field test
Advanced CHP turbine systems	Utilities-1	High	High	Policies
Autothermal reforming-ammonia	Chem-7	High	Medium	Dissemination
Membrane technology - food	Food-3	High	Medium	Dissem., R&D
Advanced lighting design	Lighting-2	High	Medium	Dissem., demo
Compressed air system management	Motorsys-3	High	Medium	Dissem.
Motor system optimization	Motorsys-5	High	Medium	Dissem., training
Pump efficiency improvement	Motorsys-6	High	Medium	Dissem., training
High efficiency/low NO_X burners	Other-2	High	Medium	Dissem., demo
Process integration (pinch analysis)	Other-4	High	Medium	Dissemination
Heat recovery - paper	Paper-5	High	Medium	Demo
Impulse drying	Paper-7	High	Medium	Demo
Smelting reduction processes	Steel-5	High	Medium	Demo
Advanced reciprocating engines	Utilities-2	High	Medium	R&D, demo
Fuel cells	Utilities-3	High	Medium	Demo
Microturbines	Utilities-4	High	Medium	R&D, demo
Inert anodes/wetted cathodes	Alum-4	High	Medium	R&D
Advanced forming	Alum-1	Medium	High	R&D
Plastics recovery	Chem-8	Medium	High	Demo
Continuous melt silicon crystal growth	Electron-1	Medium	High	R&D
100% recycled glass cullet	Glass-1	Medium	High	Demo
Anaerobic waste water treatment	Other-1	Medium	High	Dissem., demo
Dry sheet forming	Paper-4	Medium	High	R&D, demo
Biodesulfurization	Refin-1	Medium	High	R&D, demo

*note – technologies in this table are listed in alphabetical order based on industry sector

Conclusions and Recommendations for Future Work

For this study, we identified about 175 emerging energy-efficient technologies in industry, of which we characterized 54 in detail. While many profiles of individual emerging technologies are available, few reports have attempted to impose a standardized approach to the evaluation of the technologies. This study provides a way to review technologies in an independent manner, based on information on energy savings, economic, non-energy benefits, major market barriers, likelihood of success, and suggested next steps to accelerate deployment of each of the analyzed technologies.

There are many interesting lessons to be learned from further investigation of technologies identified in our preliminary screening analysis. The detailed assessments of the 54 technologies are useful to evaluate claims made by developers, as well as to evaluate market potentials for the United States or specific regions. In this report we show that many new technologies are ready to enter the market place, or are currently under development, demonstrating that the United States is not running out of technologies to improve energy efficiency and economic and environmental performance, and will not run out in the future. The study shows that many of the technologies have important non-energy benefits, ranging from reduced environmental impact to improved productivity. Several technologies have reduced capital costs compared to the current technology used by those industries. Non-energy benefits such as these are frequently a motivating factor in bringing technologies such as these to market.

MOTIVATIONS OF TECHNOLOGY ADOPTERS
AND COLLATERAL BENEFITS BEYOND ENERGY SAVINGS

Further evaluation of the profiled technologies is still needed. In particular, further quantifying the non-energy benefits based on the experience from technology users in the field is important. Interactive effects and intertechnology competition have not been accounted for and ideally should be included in any type of integrated technology scenario, for it may help to better evaluate market opportunities.

While this report focuses on the United States, state- or region-specific analysis of technologies may provide further insights into opportunities specific for the region served. Regional specificity is determined by the type of users (i.e., industrial activities) in the region, as well as the available technology developers. Combining region-specific circumstances with technology evaluations provided in this report may lead to recognition of varying needs and the appropriate policy choices for regional (e.g., state or utility) agencies.

Our selection of a limited set of 54 technologies was an arbitrary constraint based on the funding available. A number of the initial technologies screened appeared very interesting and warrant further study, but were eliminated due to resource constraints. In addition, the initial list of candidate technologies should not be viewed as all-encompassing. The authors are aware that other promising existing technologies exist, and that by their nature new technologies will be continually emerging. Ideally, the effort reflected in this report should be the start of a continuing process that identifies and profiles the most promising emerging energy-efficient industrial technologies and tracks the market success for these technologies. An interactive database may be a better choice for it would allow the continuous updating of information, rather than providing a static snapshot of the industrial technology universe.

THIS REPORT DOES NOT ADDRESS THE FULL UNIVERSE OF EMERGING TECHNOLOGIES

This report identifies and profiles many promising emerging energy-efficient industrial technologies, which can achieve high energy-savings, and have a good likelihood of success due to their economic, environmental, product quality, and other benefits. We recommend next steps that product developers and policy-makers could undertake for each of the most promising technologies. Follow-up assessments are needed to identify additional emerging technologies, and to track the emergence of the technologies profiled in this report.

RECOMMENDATIONS TO POLICY MAKERS

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Emerging Energy-Saving Technologies and Practices for the Buildings Sector as of 2004

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CONTENTS

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EXECUTIVE SUMMARY

Adopting new energy-efficient technologies and practices is key to reducing energy consumption and maintaining economic growth. As efficient technologies and practices (T&Ps) increase their market share and become conventional, new T&Ps worth promoting need to be found. Fortunately, innovators introduce new T&Ps more rapidly than the market can assimilate them. Some have greater potential than others, so periodic, systematic evaluations of emerging T&Ps serve to identify the best candidates for program development. Comparing findings over time gives additional insights into the efficiency industry's health. Our current analysis, the third in a decade, began by identifying 198 T&Ps, which were screened to select those that promise to (1) save at least 0.25% nationally when mature and accepted, (2) avoid large "lost opportunities" in new construction, or (3) capture important regional opportunities. There are still many promising technologies and practices that will save large amounts of energy. On the other hand, the number of "pure" technologies that emerged from the screening process was smaller than before. We compensated by increasing the number of "practices" that reflect new system views of older issues. Particularly attractive candidates include two distribution system improvements (leakproof ducts and duct sealing) and two practices (design of high-performance commercial buildings and retrocommissioning). Automated HVAC system diagnostics and 1 Watt standby power for home appliances complete the high priority list. We also identified 16–22 medium priority measures.

EMERGING "TECHNOLOGIES" AND EMERGING "PRACTICES"

INTRODUCTION

In 1993 and 1998, ACEEE and collaborating organizations published studies of emerging technologies (Nadel et al. 1993; Nadel et al. 1998). Each profiled and analyzed 80–100 technologies that had been recently commercialized or were expected to be commercialized in the next five years. The studies examined technologies in the appliance, lighting, HVAC, water heating, drive power, office equipment, and miscellaneous end-uses. For each technology, likely costs, commercialization date, and potential energy savings were examined, leading to lists of technologies with the largest potential for cost-effective energy savings. These studies contributed to advancing energy efficiency. The first study contributed to such initiatives as the Consortium for Energy Efficiency's residential clothes washer and high-efficiency commercial air conditioner initiatives, the U.S. Department of Defense's incandescent replacement light bulb procurement, and the U.S. Environmental Protection Agency's involvement in Lawrence Berkeley National Laboratory's aerosol duct-sealant project. The second study highlighted HVAC, lighting, and integrated new building design. It also identified large opportunities for improved appliances, water heating, onsite power production, and the building shell.

However, the information in these studies is becoming dated. Some technologies have since been commercialized and others have faced difficulties, while new technologies continue to be developed. Some of the early "low-hanging fruit" among energy-efficient technologies have already been harvested. New gains will come from other fruit, less obvious orchards, and improved methods of achieving performance in the field (practices). This project updates and revises the earlier studies. We started with reconnaissance for new technologies and practices, but also revised our methods to include region-specific and new construction opportunities.

LISTS CAN BECOME OUTDATED

OBJECTIVES

Among the objectives of this new study are:

- to identify new research and demonstration projects that could help advance high-priority emerging technologies;
- to identify potential new technologies and practices for market transformation activities; and
- to gain new insights into the technology development and commercialization process by comparing 1998 expectations with 2004's reality

SCOPE

Our scope covered the residential and commercial sectors. We included both energy-saving technologies (e.g., a new air conditioner) and practices (e.g., improved air conditioner installation procedures). In this study, we defined "emerging technologies and practices" as those that either: (a) are not yet commercialized but we judge to be likely to be commercialized and cost effective to a significant proportion of end-users (on a life-cycle cost basis) by 2009; or (b) are commercialized, but currently have penetrated no more than 2% of the appropriate market.

DEFINITION: EMERGING TECHNOLOGIES AND PRACTICES

METHODOLOGY

We identified 198 measures (technologies and practices) that might save substantial energy. Candidates were taken from lists of emerging technologies developed for the 1998 study; existing ACEEE, Davis Energy Group (DEG), Natural Resources Canada (NRCan), and Marbek Consultants databases and reports; recommendations from energy research organizations, major utility R&D departments, and state and provincial R&D institutions; recent conference proceedings; consultations with experts; and product and research announcements.

First, each measure was assigned to one of three preliminary categories: high, medium, and low potential. Low potential measures are those that are likely to have a cost of saved energy greater than current U.S. national average energy prices, or that can reduce U.S. and Canadian buildings energy use by less than 0.25%. High potential measures are likely to have a cost of saved energy less than 50% of current U.S. national average energy prices, and that can reduce U.S. or Canadian buildings energy use by 1% or more. Medium potential measures were neither "high" nor "low", or measures for which little is known, so further analysis is needed.

This study also includes several special cases, measures that would save less than 0.25% nationally, but still warrant consideration. Some are "lost opportunities," particularly for the new construction market. Because new construction is unlikely to account for more than 20% of the building stock by 2020, new construction measures otherwise could show no more than 20% of the effect of other measures. For many of these (e.g., glazing upgrades), the cost of later retrofitting is much higher. With similar justification, we include a few measures that have great potential regionally, but limited impact for the United States and Canada as a whole. Typically, these are climate-sensitive HVAC products; one example is air conditioners with evaporative condensers and high sensible heat ratios for the Southwest. The next step was further analysis of the poorly understood measures identified above, to place them more clearly in the high, medium, or low priority categories.

From this initial screen, we identified 76 candidates as likely medium and high priority emerging technologies. For each, we collected over 30 pieces of input data in a database. Each includes *market information,* a *base case,* and a *new measure* characterization for analysis. We also included the current status of the technology, the estimated year of commercialization, and the estimated measure life. Our cost data include purchase price and additional or avoided maintenance costs. Next, we developed qualitative measures of likelihood of success in the market (major market barriers, effect on customer utility, current promotional efforts, etc). These vary from 1 (difficult; multiple major barriers to overcome) through 5 (excellent chance of success; barriers clearly surmountable). *Feasible applications* is an estimate of the fraction of the appropriate building stock (such as new low rise residential) that could adopt the technology or practice.

Our outputs for individual measures are *savings,* including U.S. electricity (and peak demand), and gas *savings potential* in 2020 in GWh (million kWh) and TBtu (trillion Btu). We then computed the cost of saved energy (levelized cost) in both $/kWh and dollars per million Btu of primary energy ($/MMBtu). In some cases, the cost of saved energy is negative, meaning that the annualized capital and operating costs are less than those for the old, baseline measures. The cost of saved energy is rounded to the nearest cent, because of uncertainties in the analysis.

For this study, measures were divided into "high," "medium," "lower," "special," and "not a priority" categories, based on three factors: potential energy savings, cost of saved energy, and likelihood of success. Criteria and number of measures identified are given in Table ES-1.

Since many of the technologies and practices covered are still niche products, estimates of measure cost, savings, and commercialization date are imprecise. Due to these limitations, calculated costs of saved energy and savings potential ratings were rounded to one significant digit. 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 varies with the quality of the data available for each measure.

Savings are not additive among measures. For example, the savings from adopting an advanced air conditioning method plus an improved shell measure will be less than the savings for each measure by itself. In this case, the improved shell would reduce the baseline energy use, thus giving smaller kWh savings.

Table ES-1. Priority Levels and Distribution of Measures by Classification Parameters

Priority	Threshold for Savings	CSE, $/kWh	CSE, $/MMBtu (source energy)	Likelihood of Success	Number of Measures
high	≥ 1.0%	≤ $0.0405/kWh	≤ $3.16/MMBtu	3–5	3–6
medium	≥ 0.25%	≤ $0.081/kWh	≤ $6.33/MMBtu	3–5	16–21
low	NA	≤ $0.081/kWh	≤ $6.33/MMBtu	2–5	11–14
special	>~0.05%	≤ $0.081/kWh	≤ $6.33/MMBtu	2–5	12–22
not a priority		Fails to meet other thresholds			14–24
total					73

Notes:

To earn a "high" or "medium" priority, a measure must meet all the thresholds in the row. For example, high priority measures are those that show potential energy savings of at least 1% of projected U.S. residential and commercial energy consumption in 2020; a cost of saved energy less than half of current U.S. retail energy prices; *and* a likelihood of success rating of 3 or more. If a measure fails to meet one or more of these thresholds, it slips to the next lower priority.

The column for "Number of Measures" in this study reflects analytical uncertainty about costs (and applicability) by giving a range of measures that can be included in each category, such as 3–6 high priority measures. Typically, ranges are extended downward by a small amount (<10%) to include more measures and respond to the uncertainties in the analysis.

RESULTS

Seventy-two measures were studied in detail. Key results are summarized in Table ES-1, above.

The **high priority measures** are diverse. Two (leakproof ducts and duct sealing) are distribution system improvements and two are practices (design of high-performance commercial buildings and retrocommissioning.) Automated diagnostics complements retrocommissioning as a building operation improvement. The final measure, 1 Watt standby power for home appliances, is the only "pure" equipment measure in the high priority list. These measures are described more fully in the project report.

Seven of the 16–22 **medium priority measures** are lighting, primarily commercial measures (premium T8 lighting, one-lamp fluorescent fixtures, commercial LED lighting, and scotopic lighting). However, at least two lighting measures (airtight compact fluorescent downlights and CFL portable fixtures) are primarily residential. Twelve of the measures are primarily residential. Five of these deal with refrigeration-cycle equipment: improved refrigerators, air conditioners, and heat pump water heaters. Commercial measures include better management of networked computer energy use, and carbon dioxide-controlled ventilation to reduce fan power as well as chiller energy.

The common element among **low priority measures** is the low likelihood of success, frequently because they represent major changes from present methods and technologies. Low likelihood of success in the near term is exemplified by the very large savings associated with commercial "combined heat and power" (CHP) technologies incorporating microturbines and fuel cells, and even for residential CHP with Stirling engines.

"Special" measures have high value for specific regions or new construction, even though they may not have enough savings on a national basis to warrant national priority. About half of the special measures are feasible for new construction, but prohibitively expensive as retrofits. These measures include low energy designs and construction methods. Special also includes half a dozen measures specific to hot or hot and humid climates, typically advanced air conditioners such as the Cromer Cycle (combining desiccant and refrigerant systems in a single unit). The category also includes air conditioners optimized for hot-dry climates and two-speed pool pumps. Northern climates rate three special measures, including gas-fired absorption heat pumps, advanced condensing boilers for commercial applications, and roof-top year-round units with condensing furnace sections. Two further measures are applicable to guest rooms in the hospitality industry. These include "smart" door card keys that incorporate energy management and bathroom lighting that better matches use patterns. These may be indicative of opportunities that will arise when other industries are targeted for close examination.

Between 1993 and 1998, the number of measures attractive enough for analysis dropped by about 25%, but stabilized for this study (see Table ES-2). Similarly, the second study had only two-thirds as many high and medium priorities as the first. The current study is close to the 1998 level, but this study also includes special measures (see Table ES-1).

Table ES-2. Number of Measures by Priority—1993, 1998, and 2004 Studies

	1993	1998	2004
total measures analyzed	102	73	72
high priority	21	12	3–6
medium priority	32	21	16–22
high + medium	52	33	22–25

Note: Total for 2004 is lower than the sum of the two rows above because of overlaps: some measures are assigned H/M priority.

Twelve high-priority technologies and practices from 1998 carried over as high or medium priority in the present study. Three were dropped because they have estimated market shares above 2% (high efficiency washing machines, improved compact fluorescent lamps, and integrated commercial lighting systems). In the first two cases, large-scale market transformation programs supported market growth. In the case of washing machines, this success contributed to new 2004 and 2007 federal standards for washing machines and brought many new products to the high efficiency market. Ductwork integrity improvements and retrocommissioning have remained high priorities. Within the lighting technologies, two measures dropped lower for different reasons. General-service halogen IR reflecting lamps dropped in priority because they will not compete well with higher efficacy compact fluorescents that cost less. Thus, the market is being transformed by a competing technology, but to the same ends of greater efficiency and longevity.

Two 1998 high priority measures were dropped from this study. As far as we can find from our research, dual-fuel heat pumps have disappeared from the market. Similarly, electric integrated space- and water-heating systems are no longer available (except as ground-source heat pump components), and the gas- and oil-fired equivalents have had very low market penetration.

LISTS CAN BECOME OUTDATED

DISCUSSION

Lessons Learned and Implications of the Study

Perhaps the most important finding of this study is that the well of emerging technologies and practices continues to yield many promising measures. Including special measures for new construction or regional applicability, we find more promising measures than in the 1998 study: the sum of high and medium in 1998 was 33, compared with 22–25 this time, but this study added 12–22 special measures that warrant serious consideration. Of course, the reservoir is changing. Some of the measures that would result in the largest savings would also require the greatest changes in the present mode of operations. Combined heat and power at commercial and residential scales, using emerging technologies such as fuel cells and Stirling engines, could save well beyond 1% of projected buildings energy in 2020, but would require substantial changes in how most utilities do business and see themselves, as well as substantial cost reductions. Measures to assure ductwork integrity are another example of the need to change the business model. Achieving real results will require that industry and consumers recognize the importance of energy distribution within the building (for comfort and air quality). Finally, retrocommissioning and advanced design practices have great importance and potential, as do training, incentives, and other "humanware" services.

Our consideration of special measures in this study illustrates another trend. While the earliest study (1993) could point to a relatively small number of technologies that each promised enormous savings, the present study, particularly in special cases, finds more broadly distributed savings that are smaller, on average. The 12 high priority measures in 1998 averaged about 824 TBtu per measure; the six highest priority measures in this study average about 533 TBtu per measure. The total estimated savings from all measures is only three-quarters as large as in 1998. We believe that the analyses were systematically more conservative this time, accounting for some of the difference.

However, there is another (pleasant) surprise in this study. Several measures that are assigned relatively high priority in this study were not available on the market for consideration in the 1998 study. These notably include "Super" T-8 lights and zone-level CO_2-based ventilation control, where critical research and development were nearly complete in 1998, but not yet announced. These have prospered in the market and no longer qualify as "emerging technologies."

Recommended Next Steps

Table ES-3 summarizes the next steps for the highest priority measures.

Table ES-3. Recommended Next Steps for the Highest Priority Measures

Measure	Name	Next Steps
PR3	commercial construction 30% > code	• dissemination of successful case studies • revised fee structures for mechanical designers • client education • better software
A1	1 Watt standby power	• ENERGY STAR® program for power supplies • possible manufacturer incentive for using better power supplies • mandatory standard for power supplies
PR1	advanced automated building diagnostics	• additional research • work on standard protocols for alarm and id transmission. • case studies on value based on real demonstrations
PR4	retrocommissioning	• better define approaches and appropriate applications for different approaches • benchmarking • MT with promotion, training, and incentives
H12	aerosol-based duct sealing	• raise consumer awareness of problems and savings • utility incentives • HVAC contractors taking on value-added service • training and certification • field tests in regions with basements and crawl spaces
H11	leakproof duct fittings	• raise consumer awareness of problems and savings • utility incentives • performance-based codes and standards • duct system integrity certification • field tests in regions with basements and crawl spaces

For most technologies and practices, the next steps can be generalized as follows:

Almost by definition, emerging technologies require unbiased, third-party demonstrations to convince customers that they will perform as advertised. Products of this work should include both marketing materials and detailed analytical case studies.

For emerging practices, "infrastructure" development is even more important than demonstrations. The "inputs" include training design team members, and helping them develop better working methods. Software tools are increasingly a key infrastructure component. Frequently, infrastructure work will include support for building code revisions to accommodate new methods and technologies.

Finally, groups interested in market transformation should begin developing prototypes of appropriate programs for the measures they find most promising. This effort will both encourage the manufacturers and help identify missing pieces (such as performance certification) that are required for success. This is particularly important for programs dealing with practices (such as retrocommissioning and advanced, integrated designs), which have been less common in the past.

In combination, these recommended next steps can help pave the way for increased market adoption of these emerging technologies and practices. Finally, we recommend another assessment of emerging technologies and practices for energy efficiency for completion in about five years, in order to identify new opportunities.