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.

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 .

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.

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 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.