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FAN AND PUMP SYSTEMS: MARKETS AND PROGRAMS

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Introduction

Since fan and pump systems provide large opportunities for energy savings and account for about 40% of motor systems energy use (see Figure 1), they are a prime target for energy efficiency efforts. However, most of the available savings from fan and pumps systems require an understanding of the marketplace and good application-specific engineering, and cannot be obtained in a "cookie cutter" fashion. Because fan and pump energy use varies as approximately the cube of motor speed while flow varies directly, small changes in motor speed can have large impacts on energy use. Motor speed can be changed by varying the drivetrain (e.g., different belts and pulleys), through staging multiple fans or pumps, or through the use of an adjustable speed drive (ASD), also know as a variable frequency drive (VFD). Most end-users (and even many of the consulting engineers they hire) often lack practical knowledge regarding how best to optimize systems. Furthermore, optimization can be a time-consuming process, and time is something most customers are short of.

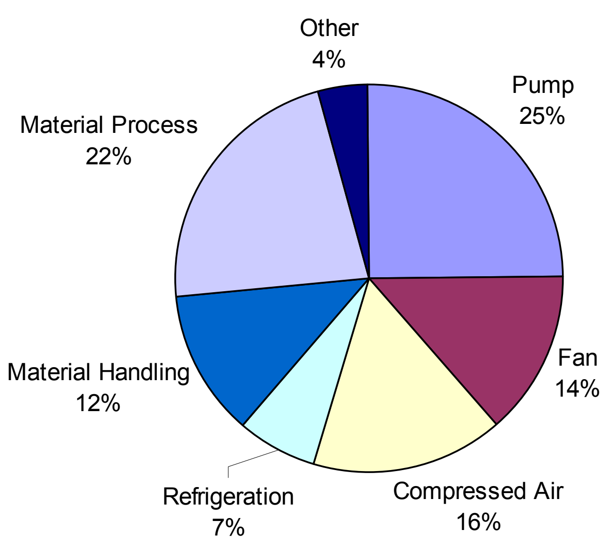

Figure 1: Motor Systems Energy End-Use (Source: Nadel et al. 2002)

This white paper is intended as a background resource for those engaged in the design and deployment of pump and fan efficiency programs. It draws important information from previous ACEEE material, *Energy-Efficient Motor Systems,* 2nd Edition (Nadel et al. 2002) and *Electric Motor System Market Transformation (*Freedman et al.1996). This paper provides an overview of the pump and fan system marketplace, and reviews past program experience. It is important to note that significant progress has been in addressing the barriers set forth in Tables 2 and 4 since Freedman et al. was published in 1996 that is not reflected in the tables.

Industrial Fan and Blower System Market

Fan and blower systems are used in a variety of applications in the industrial market. The applications can be roughly categorized as "clean" process; "dirty" process; material handling; and heating, ventilating, and air conditioning (HVAC) (see Figure 2). These categories tend to blend together and it is often difficult to differentiate and segment fans and blowers by application category.

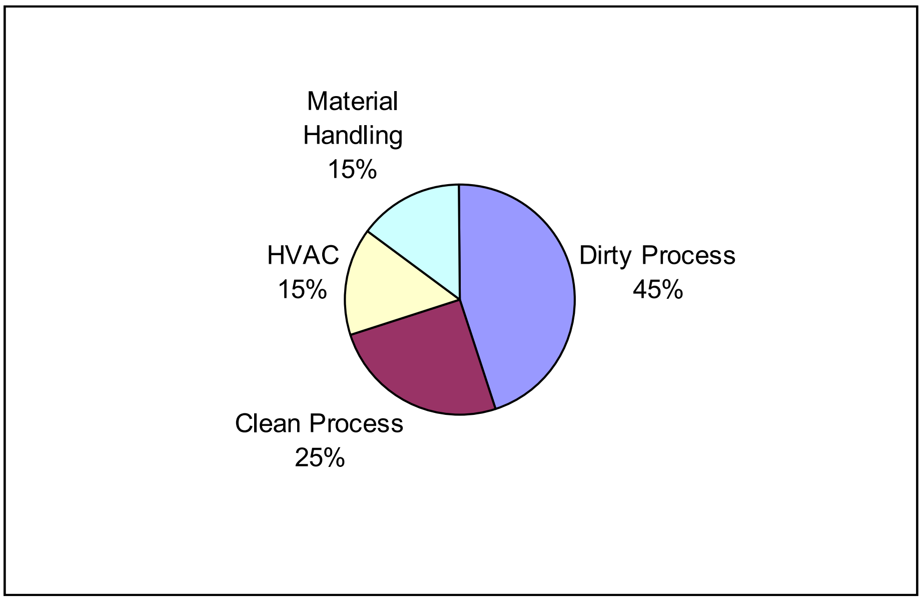

Figure 2: Industrial Fan Sales by Application (Source: Easton 1995)

Electricity consumption by the installed base of industrial fans and blowers is estimated at 45–55 terawatt-hours (TWh) per year, roughly 8–10% of total motor-driven manufacturing sector electricity consumption (Easton 1995). Centrifugal fans dominate the fan and blower market in the manufacturing sector, accounting for more than 90% of fan and blower energy consumption. An estimated 45,000–50,000 centrifugal fans are sold to the manufacturing sector each year. Axial fans (which are used primarily in commercial HVAC applications or for large flow, clean air applications in the mining, utility, and transportation sectors) make up the remainder of the market.

The industrial fan and blower market is fragmented and competitive, with no manufacturer accounting for more than a 12% market share (Easton 1995). Manufacturers sell fans and blowers through manufacturer representatives or to other OEMs, including dust collection, HVAC, oven, boiler, and pollution control equipment manufacturers, among others (see Figure 3).

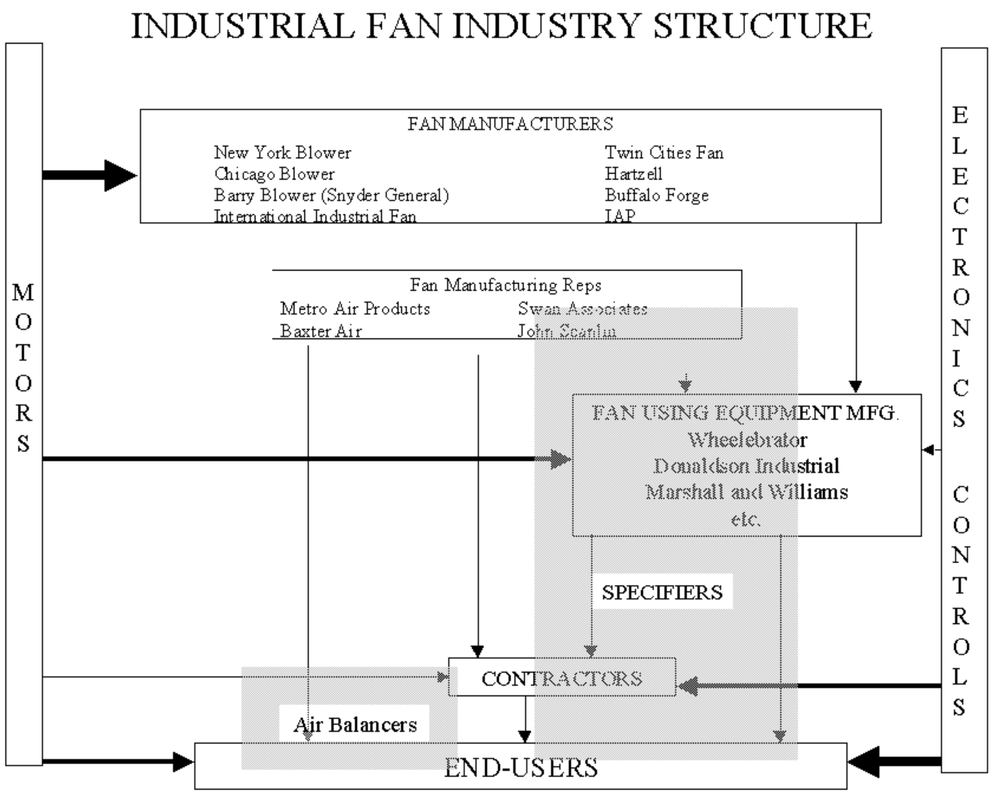

Figure 3. Industrial Fan System Market (Easton 1995)

Contractors install most fan and blower systems. Specifiers work with the contractor, end-user, and manufacturer representatives to design the system and select equipment. Finally, independent air balancing firms may be called upon to test the system after installation and certify that it meets design criteria.

Initial field research suggests that substantial further reductions in industrial fan and blower electricity consumption are possible (see Table 1).[1] Although only moderate equipment-level savings potential exists, 5-15% as noted in Table 1, these savings opportunities may be applicable to a large share of the market. Additional research is required to better quantify this opportunity. Improving system design to reduce the "system effect" in poorly designed systems can reduce consumption at selected sites. The large number of different industrial fan and blower

[1] Identifying savings opportunities requires detailed analysis of specific sites and system operation. Because fan and blower systems vary widely from site to site, predicting the total available savings potential will require a thorough understanding of current design, selection, and operations and maintenance practices by industry and application.

applications, and site-specific operating conditions limit the potential for broad-based prescriptive equipment and system solutions.

Table 1: Energy Savings Potential for Specific Fan and Blower Systems

Equipment	5–15%
Speed Control	20–50%*
System Design	5–25%

* Applies to variable flow systems and includes ASDs as well as staging multiple fans to serve a load response to varying air needs. (Source: Easton 1995)

Initial field research also suggests seven main obstacles to encouraging greater industrial fan and blower system efficiency. These deficiencies are summarized in Table 2.

Industrial Process Pump System Market

In general, pumps perform two basic functions in the manufacturing sector: pumps are either a part of the production process (process pumps) or they support ancillary systems such as cooling water loops or boiler feed systems. Process pumps are integral in the production process. These pumps supply raw materials and circulate, mix, and move materials throughout the process. They move liquors, stocks, and water in the pulp and paper production process, circulate and mix chemical products and slurries in chemical production, and move petroleum products throughout the refining process.

Pumps in the manufacturing sector consume an estimated 120–125 TWh per year, approximately 15% of total manufacturing sector electricity consumption and more than one-fifth of the sector's motor-driven electricity consumption. Pumps in the chemical, pulp and paper, and petroleum processing industries consume approximately 90–95 TWh, more than three-fourths of all manufacturing sector pumping electricity consumption. Within these three segments, process pumps account for about two-thirds of the total pump consumption, or roughly 60–70 TWh.

Several types of pumps are used in manufacturing processes for pumping different fluids at different pressures. For example, rotary pumps often handle higher pressure fluid applications, and reciprocating diaphragm pumps are used where contamination prevention is critical. However, centrifugal pumps dominate the process pump market in terms of annual unit and capacity sales, installed units and capacity, and total electricity consumption. A typical industrial process uses many size and types of pumps performing different functions.

The pump "package" is not as clearly defined as other industrial equipment packages. Manufacturers and distributors sell process pumps with or without a motor or drive. Motors are close-coupled, long-coupled, or impart power through a belt drive.

Initial field research indicates that industrial process pumping electricity consumption, estimated at 60–70 TWh per year, could be reduced by as much as 30–40% (see Table 3). However, the savings potential may be difficult to capture. Realizing the energy savings potential will require a coordinated effort by all industry stakeholders and depend on the individual system and the applicability of speed control devices such as ASDs.

Table 2: Deficiencies Associated With the Fan and Blower Systems Market

Market Deficiency	*Description*
ASDs are not used in many applications for which they are suitable due to: • lack of knowledge of applicability and • the high first-cost of ASDs.	Many users remain skeptical about using ASDs in their applications. Making changes in a process entail risk on the part of the initiator, a risk that may not seem to be worth the reward, especially if lack of application knowledge increases the perceived risk.
Lack of system design expertise creates (from an efficiency standpoint) a sub-optimal system design, specification development, and equipment selection.	System designs can be improved in terms of: designing ductwork layouts that minimize the "system" effect (where bends are too close to an outlet causing increased pressure and energy consumption), minimizing pressure drops, etc. Because fans from different manufacturers have their Best Efficiency Points at different conditions, selecting the most efficient fan for the required head and flow from a wider set of choices could save energy. Minimum equipment efficiency levels are often not included in specifications or are easily met by many models. Even when minimum fan or motor efficiency levels or specific models are written into specs, lax bidding procedures may allow lower efficiency models to be purchased.
The most efficient fan type for the specific operating conditions is often not used due to lack of information about alternative equipment designs and performance capabilities.	Airfoil blades (either metal or fiberglass) could be used in place of less efficient backward inclined blades in some applications. Likewise, backward inclined blades could replace some less-efficient radial tip impellers if users were provided with appropriate application information. Variations in practices across industries and geographies indicate the potential for improvement. Energy-efficient backward inclined fans (larger diameter, narrower and lower speed) could substitute for standard, backward inclined fans in many applications.
Equipment/system end-users and purchasers do not always specify minimum efficiency levels or energy consumption requirements	Minimum equipment efficiency levels often are not included in specifications or are too low. Ambiguous phrases such as "or equivalent model" provide loopholes for lower efficiency fans to be selected. Requiring bids to include energy consumption data (for the given operating conditions) rather than efficiency, may be more accurate, allow easier comparison among bids, and simplify life-cycle cost calculations.
End-users may base purchase decisions on first cost and do not consider the life-cycle energy cost savings associated with higher efficiency fans	By providing the operating conditions and asking the bidder to calculate (and, perhaps, guarantee, with penalties for noncompliance) energy consumption, it would be easier to select the model that provides the lowest life-cycle cost for the given conditions. Efficiency is often treated as a yes-no hurdle—any fan that passes the screen potentially could be selected. This approach does not guarantee the most rational choice. Another approach would be to select the fan that minimizes the total lifetime energy costs associated with each model by adding operating costs to the initial price (discounted for the cost of money).

Table 2: Deficiencies Associated With the Fan and Blower Systems Market (cont'd)

Market Deficiency	*Description*
It is difficult to make comparisons between different manufacturers' products because the existence of energy efficiency performance data is not widely known or easily analyzed.	Manufacturers provide detailed data on fan efficiency (fan curves) but it is not easy to calculate energy consumption for the given conditions. Some manufacturers provide software that automates these calculations for their own models, but comparing models from several manufacturers requires learning and running several software applications. No third party software directory such as Pump-Flo or MotorMaster exists for fans and blowers.
The equipment seldom operates under design conditions.	Actual conditions may vary from projected design conditions. Proper air balancing after installation or use of controls to align operating conditions and fan peak performance range could reduce energy consumption.

Table 3: Energy Savings Potential for Process Pump Systems

Equipment	5–10%
System Design	10–20%
Speed Control*	10–40%

*Similar to that for fans.

The process pump market is extremely competitive and not every manufacturer serves each process market. Manufacturers sell pumps through manufacturers' representatives and distributors, or, in some cases, directly to very large end-users (see Figure 4). Many process pumps are engineered specifically for a particular end-use application and thus are sold directly to the end-user through the manufacturer. Manufacturers and their agents (internal sales staff, distributors, and manufacturers' representatives) exert strong influences on this market, as together they play a strong role in determining pump efficiency and selection.

Pump distributors vary widely in sophistication. Some provide design, repair, and maintenance services while others simply order and obtain pumps for the end-user or contractor. Distributors use manufacturer-provided manuals, pump curves, and software to help select pumps. The information provided by the manufacturers is adequate for proper pump selection. Pump distributors play an important role in determining which pump is chosen for a job; however, they have little stake in pump system efficiency.

Mechanical contractors install most process pumps. Consulting engineers design nearly all new greenfield sites (i.e., new manufacturing facilities being constructed from the ground up) and may also get involved with system renovation or major retrofit situations. End-users often design smaller system renovations themselves. Larger end-users, particularly in the chemical and petroleum industries, often have internal process engineers who perform system design work.

A number of current market deficiencies prevent process pump systems from being more efficient. These deficiencies are presented in Table 4.

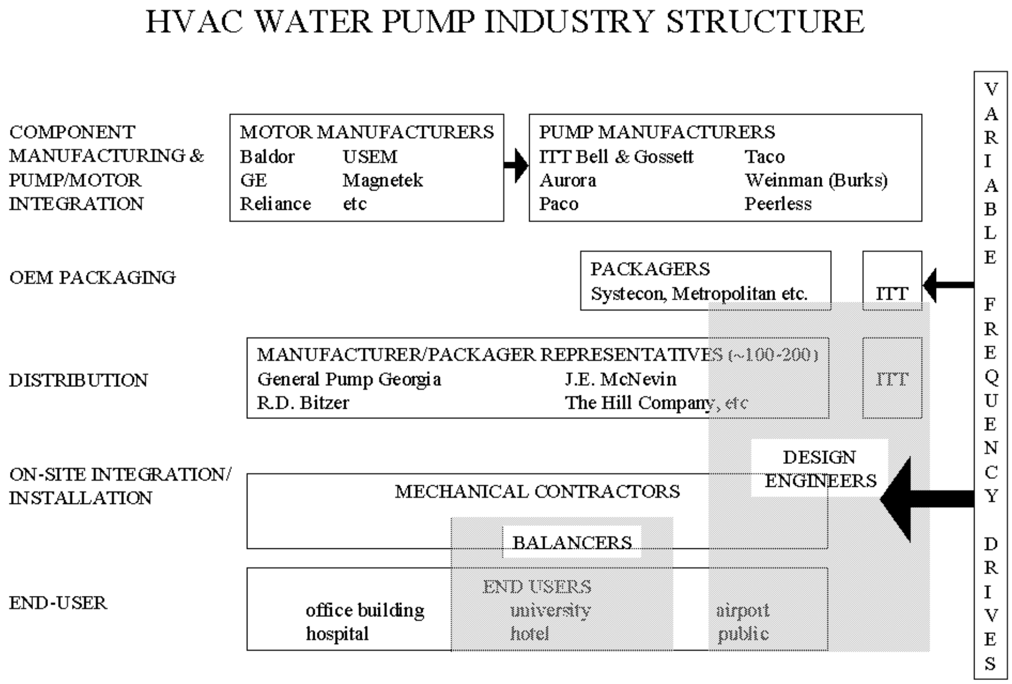

Figure 4: HVAC Water Pump Industry Market Structure

Past Pump and Fan Programs

Programs focusing on fans and pumps began around 1990, starting in Canada but then progressing to several regions of the United States. Early programs were offered by B.C. Hydro and Ontario Hydro and focused on identifying good applications for adjustable speed drives. However, this focus proposed an answer before asking which technologies make the most sense for each customer. By 1993, the Canadian utilities began several pilot projects that used a systems approach to optimize the entire motor-driven system. Due to a shift in utility priorities, these programs were discontinued before they moved out of the pilot stage but many of the people working on these programs participated in the development of a Performance Optimization Service (POS) in Wisconsin.

The Wisconsin POS program began in 1993 and was operated by the Energy Center of Wisconsin (a nonprofit organization) in partnership with the state's utilities. Under the POS, utility customer-service representatives identified candidates for POS services and a POS engineer was hired to provide the customer a quick, free engineering "walk-through" analysis of their systems. If substantial savings were projected, a feasibility study proposal was prepared to cover work needed to determine what needed to be done to improve efficiency and performance, and how much it would save the customer. If the proposal was accepted, a POS engineer collected system-load and operating data, and prepared a feasibility study report, which recommended a design strategy and detailed technical and economic impacts of the project. As the program evolved, these steps were streamlined and combined so that following the walk-through the customer was given preliminary cost and savings estimates, along with the proposal for the detailed study.

Table 4: Deficiencies Associated With the Process Pump System Market

Market Deficiency	*Description*
A lack of knowledge at the end-user, distributor, and specifier levels regarding which pump (impeller) types are applicable for particular applications (which may prevent the most efficient type for an application from being selected)	Pump efficiency is limited by the size and shape of the impeller relative to the volute or casing. With a larger impeller, relative to the size of the volute, the clearance between the impeller and the volute will be smaller and the pump will be more efficient. When specifying or purchasing a pump to move viscous fluids or those containing suspended particles or solids, the engineer or end-user often overestimates the amount of clearance required and selects a less efficient pump.
A lack of knowledge of the applicability of ASDs and the associated energy savings potential	Poor availability of application- and system-specific information regarding the applicability of ASDs prevents them from being considered in many process pumping applications. End-users and specifiers are often not well-informed regarding the energy savings potential associated with ASDs and remain somewhat skeptical regarding their performance.
Process systems are often designed to run at a number of flow rates; pumps cannot be at or very close to their best efficiency points at each flow rate.	Manufacturers often want the ability to run a system at less than full-load capacity in response to changing demand. Unless systems are designed with full redundancy and can operate in "stages" to regulate capacity, a more costly approach than simply regulating production with value or by changing motor (therefore pump) speed, pumps will not always operate near their best efficiency point.
The equipment seldom operates under design conditions.	A pump is selected with one or more specific operating conditions in mind. Because of errors in calculating the system curve and changes in pump and system performance over time, systems often actually operate at a point far from the original calculated operating condition. Under actual operating conditions, the pump selected may not be the most efficient model available.
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Difficult to compare different manufacturers' pumps because common rating and labeling guidelines are not used.	Pump performance is application-specific, depending on the system and the fluid being pumped. Manufacturers do not provide performance data at "common" operating conditions. Pump performance must be calculated for the given conditions. Some manufacturers provide software that automates these calculations for their own models, but comparing models from several different manufacturers to compare efficiency and operating cost is time consuming. Third-party software such as Pump-Flo would require the end-user to reload pump databases and recalculate for each manufacturer's models.

Utilities offered a range of incentives to customers to implement POS projects: partial reimbursement of feasibility study costs; customized rebates based on projected energy savings;

low-interest loans; and shared-savings contracts through an independent financing organization. A training program was developed with support materials for utility representatives, consulting engineers, trade allies, and end-users, with training tailored toward specific needs of each of these groups (Wroblewski 1996).

The POS program provided initial audits to 36 sites and detailed feasibility studies to 11 sites. Ultimately, however, only six customers decided to implement projects; most of the others never made a decision. An evaluation of the program attributed the low implementation rate to several factors: (1) nothing was broken; (2) it was perceived that savings were risky or cost estimates unrealistic; (3) several plants got a second opinion from a fan vendor who told them not to do the project because of feasibility or reliability concerns; (4) reluctance on the part of plant personnel to acknowledge inefficiencies in their systems; (5) payback periods that exceeded company targets; and (6) expectation/desire for financial incentives (which Wisconsin utilities were phasing out as the POS program was beginning). The evaluation also found that those customers that did implement projects did so for two main reasons: the project solved an existing problem, and/or the project was low risk and had low or no capital costs. Interviews during the evaluation found that most companies preferred to consider process changes when existing systems fail or need to be expanded. Interviewees recommended greater utility involvement in the process, including presenting the POS concept to senior management. Also, interviewees recommended educating manufacturers and design engineers about POS concepts so that these concepts could be incorporated into system designs when new equipment is installed (Bensch 1999; Sturiale 1999).

Of the projects that were implemented, four were evaluated. These projects cost an average of $48,000 and saved an average of $40,500 annually, resulting in an average simple payback period of 1.2 years. As a result of this low implementation rate, as well as the high cost of marketing and engineering, the Energy Center decided to cancel the program. Program staff felt that the concept had a lot of merit, but more work was needed to streamline procedures so that costs could be kept in check and also so that projects were more contained and easier for customers to make decisions about. For example, several of the engineers involved in the program recommended development of improved pre-screening procedures so that inappropriate sites could be better screened out prior to any onsite assessments (Bensch 1999; Meadows 2000).

Recent and Current Efforts Focusing on Particular Industries

Building on these lessons, recent efforts to capture fan and pump efficiency savings have tended to focus on particular industries and the particular fan and pumping systems that are generic to an industry. Focusing on industries allows for knowledge from one project to be applied to other projects, cutting costs. Also, word-of-mouth and case studies within an industry can be very useful in building participation. Examples of programs focused on particular industries include: work in California on municipal water and wastewater systems, and agricultural pumping systems; work in British Columbia, the Pacific Northwest, and North Carolina on lumber drying kilns; and work in the Northwest on refrigerated storage warehouses.

In 1995, DOE, EASA, PG&E, and local motor distributors identified water pumping at water and waste water treatment facilities as a major energy-saving opportunity, based on several previous demonstration projects. Using three CEC case studies at water and waste water sites as a foundation, they organized operations and maintenance pumping workshops for Northern California AWWA members. The workshops focused on how to choose motors and pumps, maintenance and operation practices, and motor and pump repair. These workshops were all standing room only. As a result, AWWA partnered with CEC and utilities throughout the state to offer workshops statewide. Based on this success, DOE, CEC, and AWWA, along with the Electric Power Research Institute and the utilities, brought the Pumping System Optimization training (discussed below) to California. They conducted six sessions in both 1997 and 1998, again to standing room only crowds. The success of the California initiative resulted in programs in other states, including New York, Arizona, and Iowa. The strength of the program has been its focus on a narrow market segment. Also, AWWA was an essential partner. Another inducement was that the initiative worked with participating states to give Continuing Education Unit hours for the workshops, which was important to many of the water and wastewater operators who needed the hours to maintain certification (Oliver 1999).

California utilities (e.g., PG&E and SCE) have also been promoting pump system improvements to agricultural customers for decades. The foundation of these programs has been a pump testing service that tests pumping systems to determine overall system efficiency, electrical motor performance, pump hydraulics, and water well characteristics. The result is a computerized report containing information on the testing results, and a recommendation on whether replacement or upgrading equipment is warranted. Where such changes are recommended, estimates of the capital and operating cost impacts for the upgraded system are provided. In recent years, many of these programs have added additional services such as free or subsidized engineering feasibility studies on energy-saving measures, pump system design analysis, and incentives for installing energy-saving measures (Conlon & Weisbrod 1998; SCE 2000).

Recent market research by PG&E found that the major barriers inhibiting good pumping practices are the perception that efficiency measures have many hidden costs, concerns that measures will not perform as advertised, and lack of information and the time needed to find trustworthy information. This research found that the PG&E pumping program was addressing the information barrier to a significant extent and other barriers to a lessor extent (PG&E 1999). A 1998 evaluation of SCE's pumping program found similar program impacts and further found that pumping system efficiency gradually increased in the 1990s (due in part to the SCE program), that program participants saved energy relative to nonparticipants, and that the market share for high-efficiency pumps was much greater in California than in a neighboring state that did not have an agricultural pumping program (Conlon & Weisbrod 1998).

However, this study also recommended developing additional intervention strategies to better address the remaining market barriers to high-efficiency pumps and good pumping system design, operation, and maintenance practices. Among the recommendations were the following: improving access to financing and other tools to reduce the first cost of more efficient equipment; developing standards for defining and distinguishing high-efficiency pumping equipment; working with municipalities to improve bidding procedures so that efficient and inefficient equipment are no longer evaluated as "comparable;" encouraging dealers to improve stocking of efficient equipment; and offering training for pumping system consultants on the value of long-term payback from investing in the acquisition of higher-efficiency and longer-lasting equipment(Conlon & Weisbrod 1998).

The N.C. Alternative Energy Corp., now Advanced Energy (AE), in cooperation with the furniture industry, North Carolina State University, and the state's electric utilities, undertook a project to demonstrate the potential of controlling airflow in hardwood lumber dry kilns. The project's goals included: understanding the drying process for furniture-grade hardwood; developing a control strategy for the fans; and evaluating the potential for savings. In furniture-grade lumber, especially some hardwoods such as oak, the control of the drying process is critical for maintaining lumber quality. The AE study developed a control strategy based on the change in the humidity in the air immediately before and after it had passed through the lumber stack to vary the fan speed. Field trials with two industrial demonstration sites confirmed that varying the airflow resulted in at least as good a lumber quality with no effect on production rates. The operators felt that the lumber quality was better with the variable air (particularly on difficult woods to dry, such as oak) though tests were not conclusive. The total energy required for a load of wood was reduced by about half. Paybacks for the fan control systems varied from 2.4 to 8.7 years depending upon motor size and kiln configuration. Following completion of the report, AE conducted a series of seminars on the topic for the Southeastern Dry Kiln Club, the industry technical association (IEL 1992).

A project to promote variable fan speed systems in softwood dry kilns was operated by B.C. Hydro for several years. The program sponsored audits of dry kiln systems in the province and recommended ASDs in applications with a 2-year simple payback or less (36% of audited kilns met this criteria). Ultimately, approximately two-thirds of the kilns in the province were audited, and of these, approximately 25% proceeded to implement the audit recommendations (Ference, Weicker & Company 1995). Similarly, industrial efficiency programs offered by the Bonneville Power Administration in the 1990s provided incentives for variable fan speed systems at many plants in the Northwest (Gordon 2000).

In the Northwest, a program has recently begun to work with refrigerated fruit storage warehouses to encourage them to install ASDs on refrigeration system evaporator fans. The program builds on several successful refrigerated storage projects in the region and seeks to use these successful projects to promote widespread application of this measure in the Northwest's large fruit industry. The initial projects resulted in significant energy savings and reduced fruit weight loss in all applications while improving the quality of the stored fruit in some applications. The program centers on educating warehouse owners—as well as vendors, contractors, and systems operators—on the benefits of ASDs in refrigerated warehouses. Project activities include a database on refrigerated warehouses and ASD installations in these warehouses, demonstration projects, and detailed reports on these case studies. Overall, the demonstration projects have reduced fan energy use by 24–78% and have a simple payback period of 1.6–21.6 years when only energy savings are considered. However, when fruit mass loss savings are also considered, simple paybacks drop to 1.1–2.9 years (Morton & McDevitt 2000; NEEA 2000).

Broad Programs

In addition to these industry-specific programs, a number of broader programs are being offered to promote fan and pump system energy savings. For example, DOE's *Industrial Best Practices: Motors* program has developed and offered a series of Pumping System Optimization Workshops. These sessions present the fundamentals of optimizing pump systems and focus on the Pump System Assessment Tool (PSAT), which helps industrial users assess the efficiency of pumping system operations. PSAT uses achievable pump performance data from Hydraulic Institute (HI) standards to calculate potential energy and associated cost savings. In 1999, DOE began a training program on how to use the PSAT software (DOE 2002).

Many utilities offer incentives for installation of ASDs in fan and pump systems. Most of these programs offer "custom" incentives for ASDs and other energy-saving measures. In these custom programs, the customer or its consultants prepares a description of the measure, its costs, and its energy and demand savings. Based on this information, the utility will provide an incentive determined according to a formula (e.g., $x per kWh saved). However, a few utilities offer precalculated incentives per unit horsepower controlled by the ASD, provided certain criteria are met. For example, National Grid USA offers incentives on a per horsepower basis for boiler water feed pumps; hydraulic pumps on injection molding machinery; chilled water distribution pumps employed in building HVAC systems; and supply, return, and building exhaust fans employed in variable air volume building HVAC distribution systems. For each of these applications, annual equipment operating hours must exceed eligibility levels set by the utility. National Grid offers precalculated incentives for these applications because it is confident that ASDs in these applications will provide cost-effective energy savings. For other potential applications of ASDs, National Grid accepts custom-measure applications but requires engineering calculations to verify that savings are significant and cost-effective. The National Grid ASD program has been popular with customers and ASD vendors because it is relatively simple to apply for and the amount of incentive is known in advance, making it easier for vendors to sell projects to customers. National Grid has been offering this program since the early 1990s, and as of 2000, has provided incentives for nearly 500 ASDs (McAteer 2000).

Conclusion

Overall, it is clear that there is a lot of interest in and experimentation with approaches for promoting fan and pump system improvements. However, none of the approaches used has yet "taken off" and produced a noticeable transformation of practices in the market. However, the targeted industry approach has made significant progress in some markets and appears promising for replication in other regions. Continued work is needed to identify additional sectors and processes that lend themselves to optimization improvements, permitting development of additional industry-focused initiatives. For example, a recent analysis of motor energy use and savings opportunities in the Pacific Northwest identified four industry areas with the most promise: irrigation using groundwater pumping; the pulp and paper industry; the mining industry; and food preservation (including food processing and cold storage) (Easton & XENERGY 1999b). Broader efforts to develop good tools and training programs are a useful foundation for these more targeted efforts. They also contribute towards the longer-term goal of increasing knowledge of motor and fan system optimization techniques by allowing these techniques to be employed across a wide range of applications. A particular training need is to provide better training on optimization techniques for the process engineers who are designing fan and pump systems today. To the extent that these designers know how to "do things right," system efficiency at the time of construction can be significantly increased.

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