Operations and Maintenance in the Glass Container Industry

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ABSTRACT

Utilities have always had a vested interest in understanding the power needs of their customers and regional industries. In the past several years, utilities have turned a curious eye towards facility operations and maintenance (O&M) as a potential target for energy services. In their role evaluating the only two O&M programs in the Northeast, the authors have identified compressed air as arguably the most worthwhile target for improved operations and maintenance procedures in the industry.

Compressed air is a significant electrical end-use at most manufacturing facilities, and few industries utilize compressed air to the extent of the glass container industry. Unfortunately, compressed air is often a significant source of wasted energy because many customers view it as a low-maintenance system. In the case of the glass container industry, compressed air is a mission-critical system used for driving production machinery, blowing glass, cooling plungers and product, and packaging.

Leakage totaling 10% of total compressed air capacity is not uncommon, and leakage rates upwards of 40% have been observed. Even though energy savings from repairing compressed air leaks can be substantial, regular maintenance procedures are often not in place for compressed air systems. In order to achieve future savings in the compressed air end-use, O&M programs must make a special effort to educate customers on the significant energy impacts of regular compressed air system maintenance.

This paper will focus on the glass industry, its reliability on compressed air, and the unique savings potential in the glass container industry. Through a technical review of the glass production process, this paper will identify compressed air as a highly significant electrical consumer in these facilities and present ideas on how to produce and deliver compressed air in a more efficient manner. It will also examine a glass container manufacturer with extremely high savings potential in compressed air systems, but little initiative to establish and perform compressed air maintenance due to an "if it works, don't mess with it" maintenance philosophy. Finally, this paper will address the economic benefit of compressed air maintenance in this and other manufacturing industries.

From a generic standpoint, it is hoped that this paper will help utilities and industrial customers alike to understand and capture some of the high savings potential of the compressed air enduse. Through the application of proper O&M procedures, industries dependent on compressed air may begin to realize the savings potential of this significant consumer of plant energy.

Defining O&M

It is useful to begin by developing a working definition of O&M measures. The following multi-faceted definition of O&M has appeared in several sources, although it most likely has its origins at Pacific Northwest National Laboratory (Parker et al. 1993). According to this definition, an item or activity can be considered O&M if it meets one or more of the following criteria:

- Any item or activity that will bring equipment back into its original design and specification,
- A repetitive activity,
- A low cost item that can be installed or performed by the O&M staff, although it may be contracted,
- An activity that is financed as an expense rather than capital,
- An item or activity that has a simple payback of less than one year, and
- An activity affecting the operation of equipment: set points, schedules, control settings, and procedures.

This useful definition reflects the essential characteristics of O&M without unnecessarily excluding non-traditional examples.

The Glass Container Industry

The Glass Packaging Institute (GPI) is the North American trade association for the glass container manufacturing industry. GPI member companies manufacture glass containers for a wide variety of product lines, including food, beverages, toiletries, perfume, cosmetics and medicine, and employ over 20,000 men and women in glass manufacturing plants in 24 states.

The GPI touts the glass container as a superior package due to its clarity, inertness and recyclability. Since a glass container is 100 percent recyclable, an old glass container can be made into a new glass container infinitely. The four principal ingredients in the glass container are sand, limestone, soda ash, and cullet, which is used or broken glass. Only sand is used more than cullet as a raw material in making new containers, and the other three ingredients are plentiful domestically. Cullet permits manufacturers to reduce energy input to their furnaces, since for every 10 percent of recycled glass used to make glass containers, up to 2-3 percent of the total energy used can be saved (GPI 1999).

Approximately 35 percent of all glass containers available to consumers are recycled. Over 35 billion glass containers were manufactured in the United States in 1997 (U.S. Census Bureau 1998).

The Manufacturing Process

Figure 1 displays a process flow diagram of the glass container manufacturing process (Brown, Hamel & Hedman 1996). As seen in the diagram, the typical manufacturing of glass containers can be broken into ten separate operations. At each stage of the manufacturing process, arrows depict all material transfers either into or out of the production step.

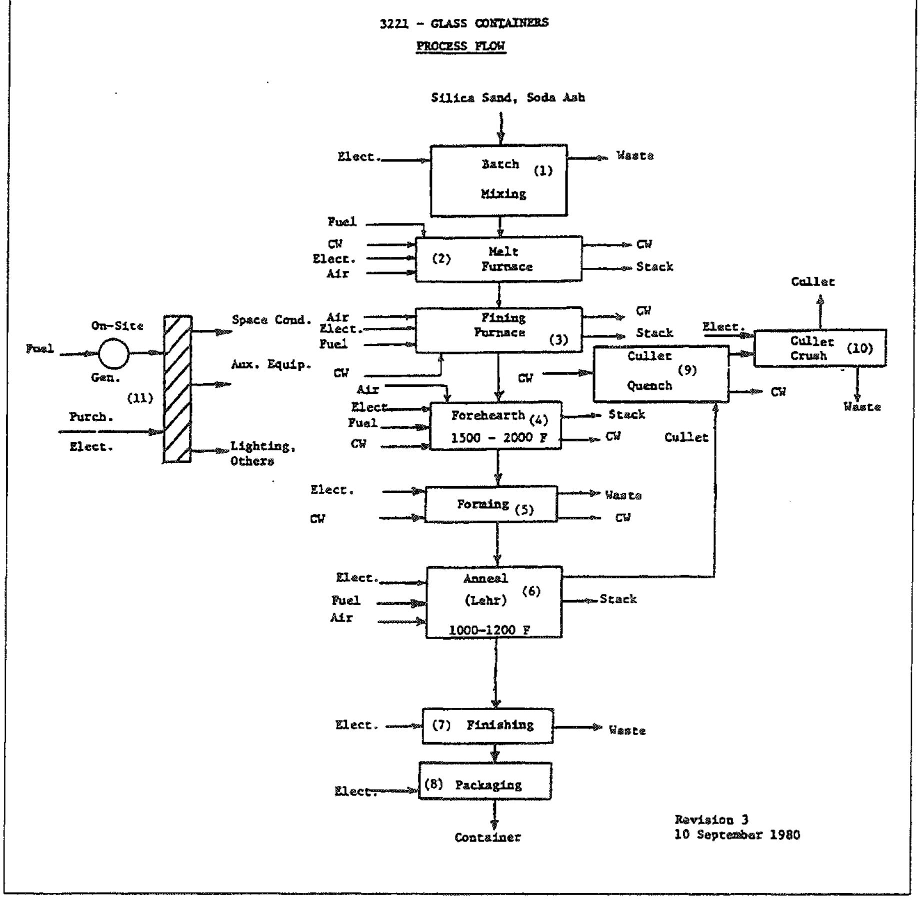

Figure 1. Process Flow Diagram of the Glass Container Industry (Brown, Hamel & Hedman 1996, 249)

First, the ingredients are mixed mechanically (1) and sent to melting furnace (2) where they are fused at high temperatures. The molten glass is boiled down, skimmed, and cooled slightly in a refining process (3). Refined glass exits the forehearth (4) as a condensed gob of hot glass. The gob is formed into shape (5), annealed (6) to relieve stress caused by manipulation, then slowly cooled. The finishing process (7) involves straightening of the solidifying mass and rejection of substandard containers. Finished containers are then packaged for shipment (8), while cullet recovered along the way is quenched (9) and crushed (10) for reuse at the beginning of the process. Table 1 details the energy and mass transfers in each operation per one pound of finished glass product.

Table 1. Detailed Energy and Mass Balance Per Pound of Glass Product (Brown, Hamel & Hedman 1996, 250-51)

INDUSTRY 3221 - GLASS CONTAINERS			INLET				OUTLET			
NO	DESCRIPTION	TEMP (F)	FLOW	TEMP (F)	MASS (LB)	ENERGY (BTU)	FLOW	TEMP (F)	MASS (LB)	ENERGY (BTU)
1	MIXING	75	SILICA SAND	75	0.640	0.0	BATCH	75	1.320	0.0
			SODA ASH	75	0.200	0.0	WASTE	75	0.020	0.0
			MGCACO32	75	0.190	0.0	HEAT LOSSES			39.2
			CACO3	75	0.060	0.0				
			CRUSHED CULLET	75	0.200	0.0				
			WATER	75	0.050	0.0				
			ELECTRICITY			39.2				
2	MELTING FURNACE	2,800	BATCH	75	1.320	0.0	MOLTEN GLASS	2,800	1.260	1,100.0
			COOLING WATER IN	75	2.000	0.0	COOLING WATER OUT	165	2.000	175.0
			AIR IN	75	4.860	0.0	STACK	1,300	4.920	1,000.0
			FUEL			4,400.0	HEAT LOSSES			2,137.5
			ELECTRICITY			117.5				
			ENDOTHERMIC REACTION			-105.0				
3	REFINING	2,300	MOLTEN GLASS	2,800	1.260	1,100.0	REFINED GLASS	2,300	1.260	900.0
			COOLING WATER IN	75	0.300	0.0	COOLING WATER OUT	175	0.300	25.0
			AIR IN	75	1.300	0.0	STACK	1,000	1.300	320.0
			FUEL			185.0	HEAT LOSSES			69.4
			ELECTRICITY			29.4				
4	FOREHEARTH	1,740	REFINED GLASS	2,300	1.260	900.0	CONTAINER GOB	1,740	1.260	670.0
			COOLING WATER IN	75	0.300	0.0	COOLING WATER OUT	175	0.300	30.0
			AIR IN	75	2.440	0.0	STACK	1,700	2.440	570.0
			FUEL			450.0	HEAT LOSSES			109.4
			ELECTRICITY			29.4				
5	FORMING	900	CONTAINER GOB	1,740	1.260	670.0	HOT CONTAINER	900	1.200	320.0
			COOLING WATER IN	75	3.400	0.0	COOLING WATER OUT	175	3.400	334.0
			ELECTRICITY			278.8	CULLET	900	0.060	16.0
							HEAT LOSSES			278.8
6	ANNEAL	1,200	HOT CONTAINER	900	1.200	320.0	CONTAINER	75	1.130	0.0
			AIR IN	75	1.850	0.0	STACK	1,200	1.850	430.0
			FUEL			600.0	CULLET	1,100	0.070	25.0
			ELECTRICITY			55.8	HEAT LOSSES			520.8
7	FINISHING	75	CONTAINER	75	1.130	0.0	FINISHED CONTAINER	75	1.000	0.0
			ELECTRICITY			27.9	WASTE GLASS	75	0.130	0.0
							HEAT LOSSES			27.9
8	PACKAGING	75	FINISHED CONTAINER	75	1.000	0.0	FINISHED CONTAINER	75	1.000	0.0
			FUEL			157.0	HEAT LOSSES			175.4
			ELECTRICITY			18.4				
9	CULLET QUENCH	75	COOLING WATER IN	75	0.500	0.0	COOLING WATER OUT	175	0.500	40.5
			CULLET (ANNEALING)	1,100	0.070	25.0	OUENCHED CULLET	75	0.130	0.0
			CULLET (FORMING)	900	0.060	16.0	HEAT LOSSES			0.5
10	CRUSHING	75	QUENCHED CULLET	75	0.130	0.0	WASTE CULLET	75	0.030	0.0
			ELECTRICITY			19.6	CRUSHED CULLET	75	0.100	0.0
							HEAT LOSSES			19.6

Figure 2 shows where the electricity is being used in the processes detailed above in Table 1. Forty-five percent of the total electrical energy required to produce a container is consumed during the forming stage. The vast majority of this energy is used to compress air that moves machine parts and blows the final container. Figure 3 illustrates the *press-and-blow* method typically employed to make glass containers. A *gob* of hot glass is dropped into a primary mold where it is pressed into a rough shape. The bottom half of the mold then is removed while a finishing mold is placed around the suspended *parison*. Finally, compressed air is blown into the hollowed parison to create the finished container.

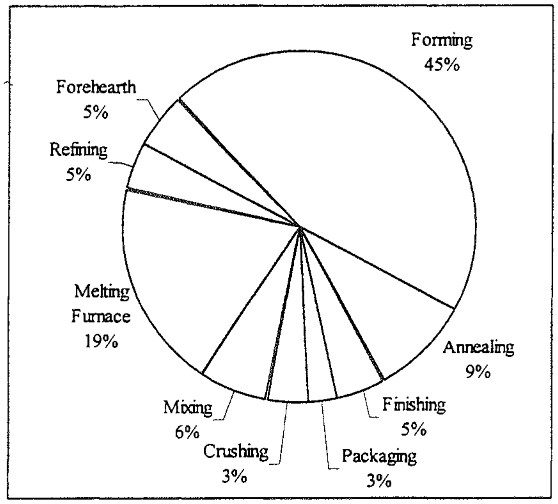

Figure 2. Operations Using Electricity in the Glass Container Process

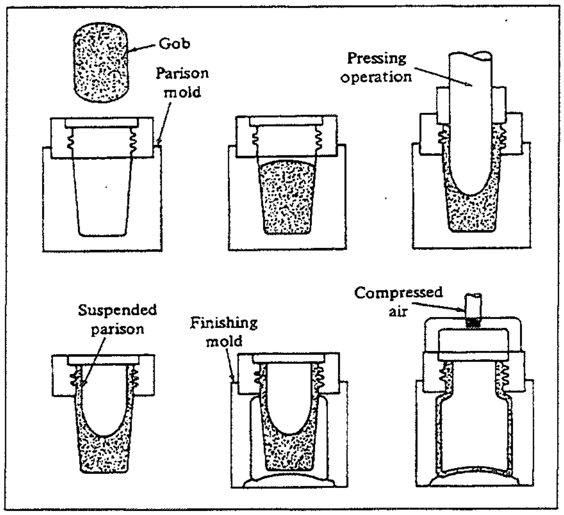

Figure 3. Manufacturing a Glass Container (Kingery 1960, 67)

Intuitively, we know that compressed air must be a significant electrical end-user at glass container facilities since it is the force that actually creates the finished product. Using data supplied by a utility in the Northeast, we compared the end-use distribution of the Stone, Clay and Glass industry (SIC32) to all other industries. Two findings immediately surfaced in Figure 4. First, the relative lighting and HVAC loads at SIC32 facilities were at most *half* of all other industries, with which those of us that have been inside glass factories would agree. And second, SIC32 facilities use approximately *twice* the amount of compressed air and process equipment electricity than all other industries.

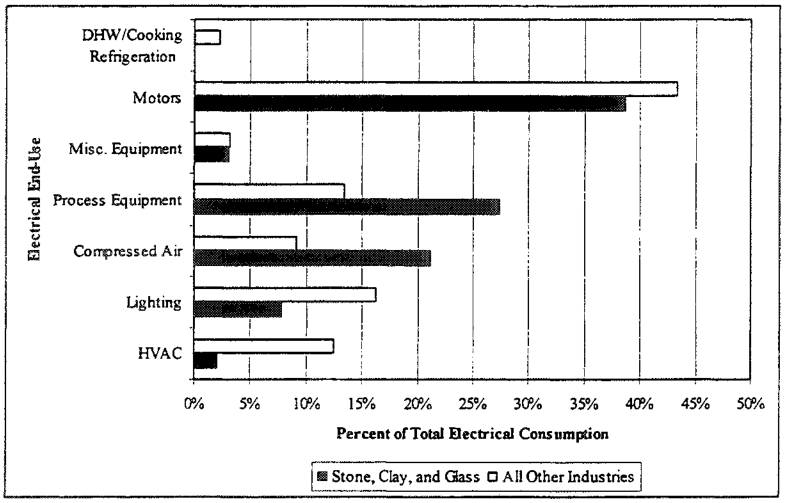

Figure 4. Comparison of Electrical End Usage in the Stone, Clay and Glass Industry to All Other Industries

Unfortunately, this data represents the Stone, Clay and Glass industry as a whole; end-use data was not available for the glass container sub-segment. However, it should be noted that the glass container industry consumed 10% and other glass industries used another 21%

of the 37,306 million kWh purchased by the Stone, Clay and Glass industry in 1996 (U.S. Census Bureau 1996).

Lessons Learned at a Glass Container Facility

Figure 5 shows the energy and demand history at a large glass container manufacturer in the Northeast. In an average month, this plant maintains a fairly steady 91% load factor while consuming 5,300 MWh at 8.1 MW of demand. As seen in the figure, there is little seasonal variation at this facility. In a typical year, this facility consumes 63.9 GWh of energy at total electric cost of approximately 4.8 million dollars.

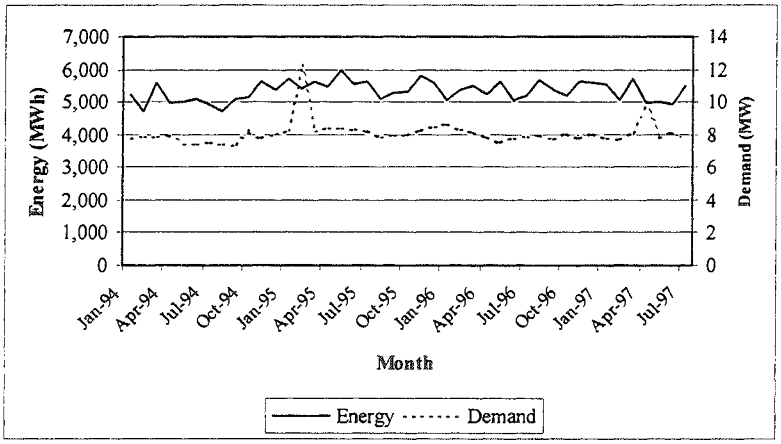

Figure 5. Monthly Energy and Demand at a Glass Container Facility

An energy audit performed at this facility in 1997 estimated that the central compressed air system consumes 13.4 GWh per year, or 21% of the facility's total electrical usage, with a total capacity of over 20,000 CFM. A comprehensive leak survey was performed which concluded that an estimated 20% leakage rate was present in the compressed air system. The audit firm estimated that repairing these leaks would result in savings totaling 2,065 MWh per year, or approximately 15% of the original electrical usage. The audit report called for the following actions to be taken at this facility:

- a comprehensive leak survey,
- adjustment of pressure regulators,
- correction of piping bottlenecks,
- cleaning condenser coils on the air dryer,
- adjusting system pressure to lowest acceptable level,
- plugging the ends of open pipes,
- installing blow-off nozzles[1] in the packaging area, and
- installing solenoid valves on carton opener machines.

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[1] Compressed air is commonly used as a motive force in a packaging process. Instead of the straight ¼" piping previously employed to eject cartons, amplifying nozzles may be employed to improve system efficiency and reduce compressed air consumption.

Unfortunately, the audit did not actually quantify the leakage rate in the compressed air systems. Instead, after the comprehensive leak survey, an assumed 20% system leakage was used to develop savings for system-wide leak repair. The following excerpt confirms that this estimate is indeed commonplace in industry:

> Of all of the maintenance failures [of compressed air systems], system leakage probably results in more lost compressed air energy than any other single factor. Plants have been observed where leakage losses are a modest 10 percent of the total compressed air capacity. Although this is "modest" by leakage standards, it is a significant annual dollar cost. Other plants have been observed with leakage rates in the range of 20 to 40 percent of total air usage. The cost of this leakage is high, avoidable, and reprehensible (Talbot 1993, 169).

To illustrate the economical impact of a simple small leak in a compressed air system, the author estimated the dollar cost of some air leakage examples for typical conditions in the following table. As seen in the table, several small leaks can have considerable financial impact. During the leak survey of the glass container facility, it was noticed that several workers had cut open the end of flexible compressed air hoses and permanently directed the output to cool themselves! While a deliberately cut hose is certainly not a "leak", it illustrates how compressed air is viewed by many as a "free" resource. Though seemingly insignificant at a plant with a $400,000 monthly electric bill, eliminating ten open 3/8" hoses could potentially save this company $137,000 per year.

Table 2. Estimate of Annual Leakage Costs (Talbot 1993, 169)

Equivalent Hole Diameter	Leakage Rate scfm	10^3 scf per year (4,000 hrs)	Cost per year (40¢ / 1,000 cf)
1/64"	0.25	60	$24
1/32"	0.99	238	$95
1/16"	3.96	950	$380
1/8"	15.86	3,806	$1,522
1/4"	63.44	15,226	$6,090
3/8"	142.74	34,258	$13,703

Air at 100 psig. Orifice with sharp edges (Coefficient of flow = 0.61).

In the end, evaluators concluded that the leak reduction only saved 462,946 kWh annually, 78% less than the original estimate of 2,065,252 kWh. Many findings - including post-retrofit metering, review of pre-retrofit data, interviews with plant personnel, and in-depth discussions with all engineers and contractors on the project - supported the conclusion that the original estimate was considerably overstated for this measure.

Annual Energy Savings (kWh)			
Measure Type	Tracking Estimate	Evaluated Estimate	Evaluated/ Tracking
Compr. Air	2,873,101	783,490	27%
EMS	430,229	382,942	89%
HVAC Maint.	767,548	593,119	77%
Lighting Ctrl.	390,354	554,435	142%
Misc.	88,195	70,956	80%
Process	1,063,892	1,208,126	114%
Total	5,613,320	3,593,068	64%

Table 3. Realization Rates for an O&M Program by Measure Type

Table 3 presents some results from the O&M evaluation which included the aforementioned glass bottle plant. As evidenced in the figure, the compressed air end-use suffered tremendously with a realization rate of only 27%. It should be noted that the bottle plant represented one of two large compressed air measures studied during this O&M program evaluation. At the other site, low flow nozzles had been proposed for a facility which previously used air from open-ended copper tubing as an ejection means in a production process. Unfortunately, the nozzles installed as part of the program failed to produce enough force to eject the parts, and the customer removed the majority of the nozzles. More preliminary research, or perhaps even testing, of the nozzles could have made this measure successful. In the end, the customer installed variable flow nozzles at this own initiative which met the needs of all his product.

So What Can Be Done?

Compressed air is a significant electrical end-use at many manufacturing facilities, but unfortunately, it is often a large source of wasted energy. While interviewing utility and industry personnel for an O&M baseline study, the authors have identified numerous instances where interviewees have suggested compressed air systems as an end-use that can benefit from improved O&M. Interviewees often state that compressed air systems are a big energy user and are often oversized and universally leaky. One subject referred to a compressed air project that saved ten thousand dollars a month through plugged air leaks.

Another suggestion was that industry requires significant education on operations and maintenance. Consistently, it was commented that to really impact O&M, it is not effective for utilities and energy service companies to merely offer financial incentives to end-users. It was emphasized that education and training in how to properly perform O&M on equipment and systems may be paramount to a successful O&M program whose goal is to diminish its intervention over time. Yet training alone often is not sufficient to influence improved O&M, as these practices require the commitment of facility personnel. Some related suggestions included holding seminars, conducting breakfast training sessions, or generating a customer O&M newsletter. Some respondents suggested offering training courses at local colleges on O&M, or holding O&M certification classes or seminars at the utility. Literature or brochures specifying maintenance schedules or other specific equipment maintenance issues may be an effective way of educating others also. Ultimately, getting maintenance staff to implement improved O&M on their own is a critical part of any market transformation effort, and education and training is a necessary component of that program design.

Manufacturing was identified as having a particular interest in O&M due to their high cost of operation. These customers are looking for ways to reduce their operating costs, of which energy comprises a significant portion. In fact, one respondent estimated that 15–20% of a manufacturer's budget is energy costs. Manufacturing was described as an open market that regularly looks at O&M as an integral part of increasing profits through reduced energy costs and potentially increased or enhanced production.

Utility personnel and audit engineers must be sympathetic towards the concerns of the large manufacturing customer. Manufacturers were nearly universally described as being primarily interested in manufacturing a product, with energy conservation or any other business considerations secondary to that goal. This may cause some manufacturers to be overly cautious about new O&M improvements that may inadvertently affect production. In the case of the bottle manufacturer: the only thing that mattered about the compressed air system at this facility was keeping it running well above demand. A momentary reduction in air delivery here would have meant discarding hundreds of ill-formed bottles as the pressure drop reached the bottle forming machines. As such, maintenance personnel were highly unreceptive to the idea of changing the compressed air system in any way. Some people close to this project attributed this "if it works, don't fix it" mindset as stemming from management at this plant.

In short, there are many substantial barriers to overcome in getting manufacturers to understand the consequences of poor compressed air system operation, while still ensuring uninterruptable compressed air delivery. The challenge for these customers is to focus O&M on items that ultimately will increase the performance of their production and positively impact their core business.

The Compressed Air Challenge

The U.S. Department of Energy (DOE) kicked-off of the Compressed Air Challenge on January 13, 1998. This program is a public/private initiative to promote the efficiency of compressed air systems, a power source which is considered industry's "fourth utility." Optimization of these systems promises improvements of 20-50% based on "best practices." The Compressed Air Challenge will work to 1) improve the efficiency and productivity of U.S. industries, 2) form a public/private partnership to deliver information and technical advice, 3) work with existing market structures to effect a transformation of the market, and 4) contribute to meeting U.S. Climate Change goals.

The Compressed Air Challenge offers five key recommendations to users of compressed air (OIT 1999):

1. *Calculate compressed air as a cost of production.* Compressed air is considered industry's fourth utility, but is seldom considered as a contributing cost of production. Instead, compressed air costs are typically blended into overhead and often thought of as "free." Such ambiguity can hide cost savings that can positively impact your bottom-line and affect your ability to account for production costs.
2. *Control the energy costs at the source.* Existing compressed air systems in the United States consume an estimated 90 billion kWh/year of electricity. The energy being used to produce and treat compressed air can be substantial. Even the smallest compressed air system can be a relatively large source of energy consumption and cost.
3. *Balance your compressed air system and save.* Many of today's compressed air systems have been "pieced together" over the years in an attempt to meet the growing needs of production and facility expansion. The result is often an unbalanced system with various components negatively interacting to create artificial demands and poor air quality. This missed opportunity can have a great impact on both man-hours and production.
4. *Sharpen your competitive edge.* Compressed air is vital to the operation of nearly every industrial plant. An efficient compressed air system can increase productivity and ensure better product quality. The more reliable your compressed air system, the more cost effectively you can produce your product—not to mention on-time delivery and increased customer satisfaction.
5. *Optimize your compressed air system.* Compressed air energy can cost seven to ten times more than electrical energy when it comes to doing mechanical or process related work. This valued form of energy is worth maximizing. An optimized system ensures that efficient and effective compressed air is available for the lowest possible cost with minimal environmental consequences.

Conclusion

It should be clear that compressed air is a significant electrical end-use at many manufacturing facilities, but especially the glass container industry. Much work needs to be done to change the perception that compressed air is a low-maintenance system, or that air compressor energy is a production cost and not overhead. Substantial leakage rates upwards of 40% are present in industry today, and this leakage has a significant and *avoidable* economic impact on American manufacturing. It is hoped that efforts like the Compressed Air Challenge will help industry begin to realize the savings potential of this significant consumer of plant energy.

References

Brown, Harry, B. Hamel, B. Hedman. 1996. *Energy Analysis of 108 Industrial Processes*. Liburn, Ga.: The Fairmont Press, Inc.

Glass Packaging Institute (GPI). *Glass Packaging Institute*. http://www.gpi.org. Accessed February 18, 1999.

Kingery, W. David. 1960. *Introduction to Ceramics*. New York, N.Y.: John Wiley & Sons, Inc.

Office of Industrial Technologies (OIT). *Compressed Air Challenge, Get Smart About Compressed Air*. http://www.knowpressure.org. Accessed February 18, 1999.

Parker, S., K. Gaustad, R. Szydlowski, D. Winiarski. 1993. *Industrial Operations and Maintenance Demand-Side Management Resource Development: Literature and Data Review*. Richland, Wash.: Pacific Northwest Laboratory.

Talbot, Edwin. 1993. *Compressed Air Systems: A Guidebook on Energy & Cost Savings*. Lilburn, Ga.: The Fairmont Press, Inc.

U.S. Census Bureau. 1996. *1996 Annual Survey of Manufacturers*. "Statistics for Industry Groups and Industries." M96(AS)-1. Washington D.C.: U.S. Department of Commerce, Economics and Statistics Administration.

U.S. Census Bureau. 1998. *Glass Containers Current Industrial Report*. M32G(98)-11. Issued January 12, 1999. Washington D.C.: U.S. Department of Commerce, Economics and Statistics Administration.