OPPORTUNITIES FOR ENERGY EFFICIENCY AND DEMAND RESPONSE IN CORRUGATED CARDBOARD MANUFACTURING FACILITIES

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ABSTRACT

Corrugated cardboard manufacturing is an energy intensive process, in both electric power and steam. Based on the US Census Bureau, there are approximately 1,733 corrugated and solid fiber box manufacturing facilities in the United States. The corrugated and solid fiber box manufacturing enjoyed a growth in number of plants of 4.9% between 1992 and 1997 (U.S. Census, 1997).

In this paper, details of the processes in corrugated cardboard production from an energy consumption viewpoint will be discussed, current prevalent practices in the industry will be elaborated and potential measures for energy use and cost savings will be outlined. The results from detailed energy audits of 12 large corrugated cardboard production plants in California will be discussed, their energy consumption will be compared, and potential savings on the national scale will be addressed.

INTRODUCTION

Based on the 1997 US Census Bureau, there are 2,834 paperboard container manufacturing facilities in the country, from which over 1,700 manufacture corrugated and solid fiber boxes. The value of shipments for the corrugated cardboard industry is approximately 25.5 billion dollars.

Corrugated cardboard manufacturing can be a very energy intensive process. Significant amounts of steam are used in the corrugating process for heating the paper to make it pliable. Compressed air contributes a fairly significant portion to the manufacturing process' electrical energy usage. Other major portions of the electrical energy usage in the corrugated cardboard facilities are due to lighting and production equipment.

MANUFACTURING PROCESS

The manufacturing of corrugated cardboard can be broken down into two parts: the front end and the back end. The front end of the manufacturing process consists of converting the paper rolls to corrugated cardboard sheets. A typical process flow diagram for manufacturing corrugated cardboard (front end) is presented in Figure 1.

Major processes involved in the front end corrugated cardboard manufacturing process include but are not limited to the following:

- Paper is steam heated to form the linerboards (outer layers of cardboard)
- Paper is steam heated and corrugated to form the 'medium' of the cardboard
- Top and bottom linerboards have adhesive (glue) applied to and attached with 'medium' to form cardboard
- Cardboard is pressed together with hot plates to remove excess moisture and to allow the glue to set.
- Slitters cut the cardboard to desired lengths and widths and add score lines for folding.

The back end of the corrugated cardboard manufacturing process may involve operations such as printing, laminating, waxing, etc. The other processes may include but are not limited to:

- Flex-folder gluer prints, folds and glues the cardboard into knocked down boxes
- Die cutters cut cardboard sheet into shape desired for finished box design.
- Application of cold set adhesive for lamination of printed cardboard

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- Application of a thin layer of wax to the corrugated cardboard.

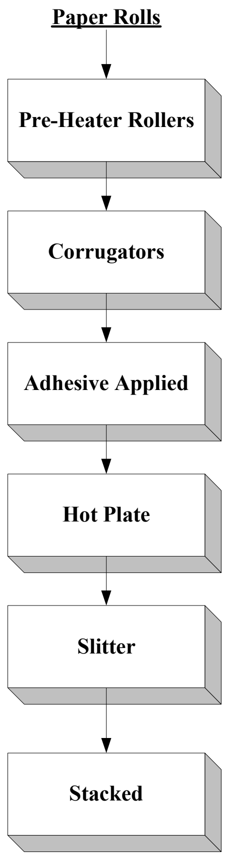

Figure 1 – Typical Process Flow Diagram of Corrugated Cardboard Manufacturing (Front End)

ASSESSMENT PROCESS

In this paper we will utilize data from twelve of the corrugated cardboard facilities that we have audited to examine the energy uses in typical corrugated cardboard manufacturing facilities. Electrical energy and natural gas energy usage and costs were often extracted from one year's worth of energy bills prior to each audit to determine the annual electrical and natural gas loads of the facilities to be studied. This data was later used to perform an energy balance of each facility's electrical and natural gas energy consuming equipment and provided a basis for comparing an individual facility's energy usage with that of other similar facilities in the study. Table 1 summarizes the electrical and natural gas energy consumption and costs for the twelve facilities included in this paper. The table also includes the energy intensity for some of the plants.

Corrugated cardboard manufacturing facilities have significant electrical and natural gas energy usage. Some of the major energy users include:

- Lighting – mainly for warehouse storage areas
- Various blowers and suction systems – used for collecting trimmed edges off of the cardboard sheet
- Significant amount of compressed air for pneumatics, blowing, drying, etc.
- Significant level of steam usage for heating rollers and hot plates to form cardboard layers
- Production motors – including corrugators, die-cutters, and other drive motors used in the manufacturing process

TABLE 1 – SUMMARY OF ELECTRICITY AND NATURAL GAS USAGE AND COSTS*

Facility	Process	Facility Size (ft^2)	Electricity Usage (kWh/yr)	Natural Gas Usage (therms/yr)	Total Energy Costs ($/yr)	Energy Usage Intensity
Plant A	Front End, Cold Lamination & Die-cut	55,000	1,237,440	70,830	159,416	0.066 kBtu/ft^2
Plant B	Front End, Die-cut & Flexo	350,000	6,068,690	820,830	878,445	0.079 kBtu/ft^2
Plant C	Front End, Die-cut & Flexo	200,000	3,832,953	378,900	590,058	N/A
Plant D	Front End, Die-cut & Flexo	435,600	8,568,582	966,110	1,064,891	0.082 kBtu/ft^2
Plant E	Front End, Die-cut & Flexo	370,000	6,570,926	538,450	737,983	0.11 kBtu/ft^2
Plant F	Front End, Die-cut & Flexo	200,000	3,670,281	350,390	429,670	0.075 kBtu/ft^2
Plant G	Front End, Die-cut & Flexo	138,300	5,287,758	816,210	1,015,862	N/A
Plant H	Front End, Die-cut & Flexo	261,360	4,966,970	601,410	794,260	N/A
Plant I	Front End only	76,000	2,485,100	489,103	364,274	N/A
Plant J	Front End & Die-cut	60,000	739,884	62,884	165,839	N/A
Plant K	Front End only	203,000	5,113,530	629,172	1,033,532	N/A
Plant L	Front End & Flexo	200,000	5,150,400	276,691	799,042	N/A

ENERGY USAGE

As mentioned before, an energy balance of each facility's electrical and natural gas energy consuming equipment would be made, which provided a basis for comparing an individual facility's energy usage with that of other similar facilities in the study. Figure 2 shows a typical electrical energy distribution pie chart for a typical corrugated cardboard (front-end only) manufacturing facility.

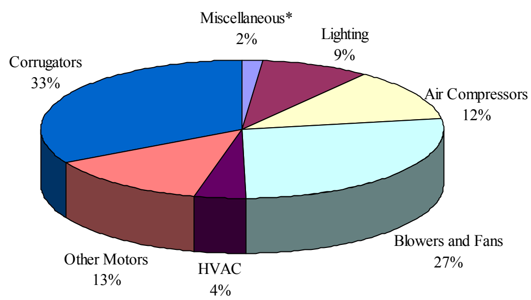

Figure 2 – Electrical Energy Pie Chart for a Corrugated Cardboard Manufacturing Plant

Figure 3 shows a typical electrical energy distribution pie chart for a corrugated cardboard manufacturing facility with die-cutting and Flexo-folder gluer operations. Variations from plant to plant should be expected for various back-end operations.

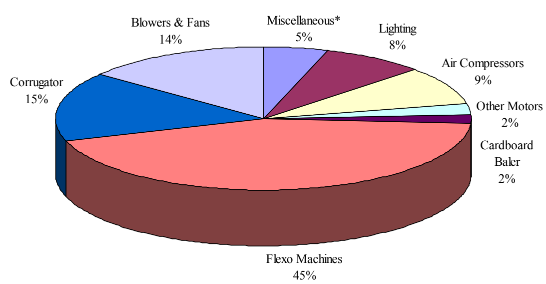

Figure 3 – Electrical Energy Pie Chart for a Corrugated Cardboard Manufacturing Plant with Die-Cut and Flexo Operation

Figure 4 shows an overall energy (both electrical and natural gas) distribution pie chart for the same corrugated cardboard manufacturing facility (front-end operation only) as shown in Figure 2 above. Again, variations from plant to plant should be expected.

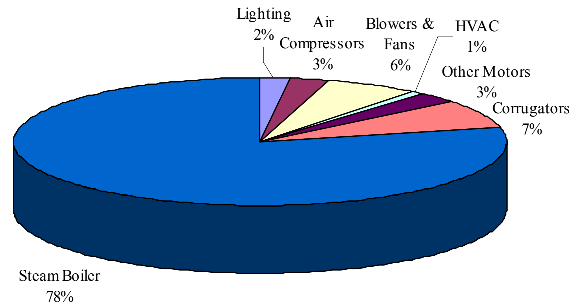

Figure 4 – Overall Energy Pie Chart for a Corrugated Cardboard Manufacturing Plant

MAJOR OPPORTUNITIES IN ENERGY EFFICIENCY

Industrial Assessment Centers (IAC), a Department of Energy program, have performed over 240 assessments of corrugated cardboard manufacturing facilities throughout the United States. Information regarding each of these audits including the recommendations made for the various energy audits and the implementation rates of various energy efficiency measures can be found in the IAC database.

Our experience in detailed audits of corrugated cardboard manufacturing facilities has resulted in identification of numerous energy savings opportunities. Table 2 shows some of the more highly recommended energy efficiency measures that we have recommended as well as the statistics for how often we have recommended them. This table also shows the statistics for how often these measures were recommended by IACs nationally and the overall implementation rate of these measures based on data gathered from the IAC database. Also included is the typical range for simple payback period of each measure listed in the table based on the audits that we have performed.

Energy Efficiency Opportunity	Recommended in the Present Study** (%)	Recommended by IAC** (%)	IAC Implementation Rate (%)	Typical Simple Payback Period* (years)
Steam System				
Repair Steam Leaks & Traps	69.2	10.8	81.48	0 – 0.2
Insulate Hot Plates on Corrugator	46.2	25.3	36.51	0.3 – 1.5
Install an Economizer to Preheat Boiler Feedwater	46.2	8.8	27.27	0.8 – 5.5
Insulate Steam and Condensate Return Pipelines	69.2	20.1	64.00	0.6 – 3.3
Tune and Adjust Boiler Air-to-Fuel Ratio	15.4	29.7	60.81	0.3 – 0.4
Compressed Air System				
Reduce Air Compressor Discharge Pressure	30.8	22.5	32.14	0 – 2.1
Replace Compressed Air Applications with Blowers	30.8	5.6	35.71	1.4 – 2.9
Repair Compressed Air Leaks	53.8	43.0	72.90	0 – 0.2
Buildings and Grounds				
Install High Efficiency Lighting	76.9	77.5	55.96	1.4 – 4.0
Install Occupancy Sensors and Light Sensors	61.5	15.7	41.03	0.2 – 3.2
Utilize More Efficient Light Source	23.1	16.9	59.52	1.5 – 3.6
Combined Heat and Power				
Install Cogeneration System	15.4	4.0	0.0	~1.4
Other Measures				
Install Energy Efficiency Motors	84.6	42.6	66.98	0.5 – 3.0
Replace Standard V-Belts with Cog-Type Belts	30.8	30.1	52.00	0.6 – 0.9
Install Variable Speed Drives	23.1	6.4	12.50	0.9 – 4.2
Turn Off Equipment When Not In Use or Interlock with Production	30.8	9.2	52.17	0 – 0.9

TABLE 2 – SUMMARY OF MOST RECOMMENDED ENERGY EFFICIENCY MEASURES

* These are based on audits presented in this paper.
** The percentage is the number of times a measure was recommended divided by the total number of facilities audited.

The measures shown in Table 2 can be applied to virtually any industrial facility. Summaries of some of the major efficiency opportunities identified specifically in the corrugated cardboard industry are briefly described below:

Heating System

As seen in Figure 4, the heating system constitutes a major portion of a corrugating cardboard plant's total energy usage. Steam is used for heating the paper and hot plates to form the corrugated cardboard. Significant levels of energy savings can be achieved through implementation of some measures that we have recommended in our audits.

<u>Insulate Hot Plates on the Corrugator</u>

In all of the facilities that we have audited, the undersides of the heating plates of the corrugators and the steam and condensate return lines were not insulated. In many of the cases, the temperature of these hot surfaces was over 350°F. Bare pipelines or surfaces with temperatures greater than 120 °F should be insulated to reduce heat loss to the ambient air. Reduced heat loss will translate into natural gas cost savings. In the plants that we have audited, energy cost savings of thousands of dollars could be realized due to proper insulation of the hot surfaces mentioned. This measure typically pays back for itself in less than one year.

Control Steam Usage to Equipment
In a few of the facilities that we have audited, steam was flowing through the equipment (e.g. glue mixer, corrugator rollers, etc.) even when the equipment was not in operation. This represents wasted thermal energy (heat), resulting in higher steam production requirements from the boiler to meet the system needs, which translates directly into increased natural gas usage by the steam boiler. Steam can be turned off or reduced in flow to the equipment when they are not in operation. Natural gas energy savings of approximately 2% can be realized due to turning off or reducing the flow of steam to equipment during periods of non-production.

Compressed Air Systems
Air compression can be a significant portion of the electrical energy usage in corrugated cardboard manufacturing facilities. Major sources of air consumption include air jets used for blowing off scrap cardboard pieces, pneumatics, and air leaks. Some potential measures for energy efficiency with compressed air usage are listed in Table 2 and many of these measures can be applied to not just the corrugated cardboard industry but to other industries as well.

Buildings and Grounds
Some of the more specific lighting energy efficiency measures that we have recommended include but are not limited to the following:

- Replacing 400-Watt Metal Halide Lamps with 360-Watt Metal Halide Lamps
- Replacing High Intensity Discharge (HID) Lamps with High Intensity Fluorescent Lighting
- Installing Bi-Level Controllers on HID Lamps
- Installing Skylights in Manufacturing Areas

Combined Heat and Power
Combined heat and power (CHP, the same as cogeneration) may be a good option for certain corrugated cardboard manufacturing facilities. This is due to the fact that both heating and electrical energy are required simultaneously. Although the cogeneration system will not be able to produce high-pressured steam that the facilities typically need for the rollers and hot plates, heat from the exhaust gas can be recovered and used to preheat the boiler feedwater before entering the boiler. However, due to the high initial capital costs and often long payback period of a combined heat and power system, this measure is not recommended as frequently in our audits.

Other Measures
Some of the other specific measures that we have recommended to the corrugated cardboard facilities that we audited include but are not limited to the following:

- Interlock Suction Fans with Flexo Machine Operation
- Install Photoelectric Sensors to Control Shredders and the Associated Blowers
- Turn Off the Hogger Drive and Blower When Not In Use
- Replace Suction Blower with Larger Motor with Adjustable Speed Drive Installed
- Install Smaller Blower Motors
- Replace Electric Starch Heaters with Gas-Fired Heaters

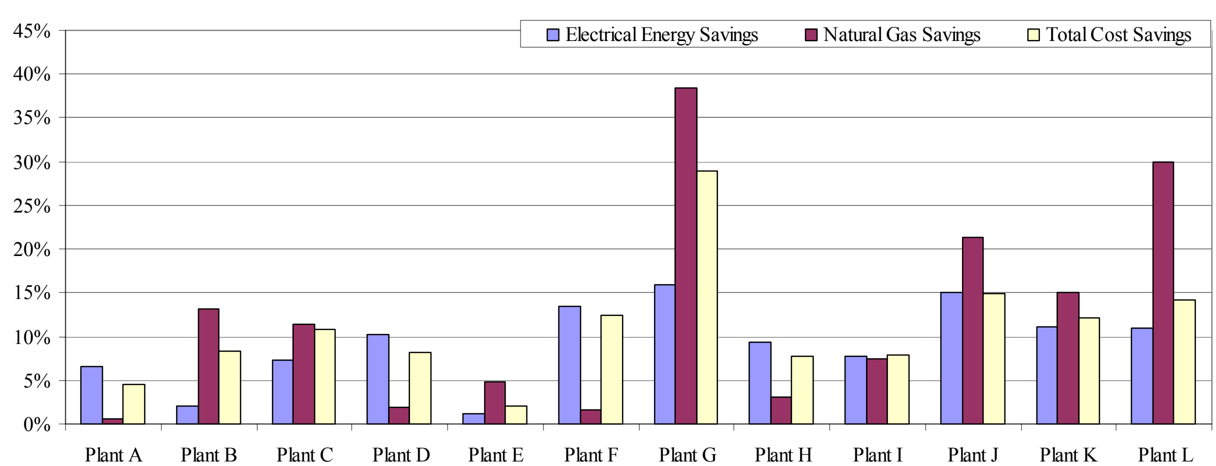

Figure 5 – Total Electrical, Natural Gas and Cost Savings Percentages of Twelve Facilities Audited by BASE

Figure 5 shows the total electrical and natural gas energy savings percentages for each of the twelve corrugated cardboard manufacturing facilities that we have audited as well as the overall total cost savings. Table 3 shows the total cost savings that can be realized to due implementation of our recommendations and the overall simple payback periods for each of the audited facilities.

TABLE 3 – SUMMARY OF ENERGY COST SAVINGS AND SIMPLE PAYBACK PERIOD

Facility	# of Measures	Total Energy Cost Savings ($)	Overall Simple Payback Period (yrs)
Plant A	3	7,157	1.8
Plant B	9	73,154	0.8
Plant C	8	63,482	1.3
Plant D	9	87,768	2.5
Plant E	7	14,918	1.6
Plant F	7	53,307	0.7
Plant G	14	294,544	0.3
Plant H	13	61,553	0.8
Plant I	9	28,945	1.1
Plant J	9	24,759	2.9
Plant K	12	124,854	0.8
Plant L	18	113,640	1.2

MAJOR OPPORTUNITIES IN DEMAND RESPONSE

In recent years, due to high electrical energy demand and rotating outages in California, demand response programs were created to give incentives to businesses for reducing their electric load during periods of extreme usage. These demand response programs are increasingly gaining popularity, especially in manufacturing facilities where potentials lie for shedding a portion of the electrical load during critical periods of usage. Recently we have incorporated this aspect into our energy audits and a few of the measures that we have recommended to corrugated cardboard facilities include but are not limited to the following:

Delay Operation of Flexo-Machines, Trim Hogger System and Air Compressor with Advance Notice

It is suggested that the facility delay the operation of the Flexo-machines, the trim hogger system, and the large air compressor in order for the plant to shed electrical load during critical periods of usage (which may be invoked 12 days during the summer season). Based on electrical power measurements and a facility energy balance, it is estimated that delaying the operation of these equipment when called for by the utility company on critical days (given one day's advance notice) can reduce the electrical demand by slightly over 600 kW. If the operation of the Flexo-machines, trim hogger system, and large air compressor can be delayed for the duration when called for by the utility company, the facility can realize an annual energy credit of over $14,000 per year.

Reschedule Facility Operating Hours

It is recommended that the facility shift its schedule so that it operates during part-peak hours to reduce the 'peak' period usage and demand charges during the summer months. Electricity is charged at this facility based on the usage and demand requirements of the plant at different times of the day. The time of use intervals are divided into three periods: Peak, Part-Peak, and Off-Peak. The Peak period lasts for six hours from noon until 6:00 p.m. for the summer months. Shifting production out of the 'peak' period during the summer months will result in significant avoided electrical costs. In one of our case studies, this recommendation can result in an annual electrical cost savings of over $100,000 per year.

A SPECIFIC CASE

In order to indicate the level of savings in one of these types of plants, a specific case is presented here. The plant is a large corrugating cardboard plant located in California with energy costs totaling over $1 million per year. Table 4 on the following page shows the summary energy usage savings and cost savings for this plant. The energy efficiency measures identified in this plant can potentially save the plant over 11% in electrical energy usage and over 15% in natural gas energy usage. Total recommended measures can result in over 12% energy cost savings for this plant. In following up with the plant approximately one year after the audit, the plant had already implemented two of the recommended measures (EEO No. 1 and 8 in Table 4) and was in the process of planning to implement seven other measures (EEO No. 2, 3, 5, 7, 9, 10 and 11) within the next few years.

BENCHMARKING

Benchmarking is the process by which a facility's performance can be compared to the performance of other facilities with similar characteristics. The purpose of benchmarking is to continuously improve levels of performance or service by identifying where changes can be made in how things are done. However, to be effective, there is a need to ensure that comparisons are valid, meaning that the facilities are similar and similar measurements and data are used for benchmarking. Benchmarking typically compares the facilities based on the annual energy use intensity (EUI). Comparing annual energy use intensities (EUIs) can quickly show the energy performance of a facility compared to others. For manufacturing facilities, benchmarks can be made based on the energy used per unit of production. Table 1 shows the EUI for several facilities where production information was available to the audit team. These can provide a preliminary basis for comparison. However in order to more accurately benchmark one facility against another, the manufacturing processes in both facilities should be fairly similar. For example, benchmarking a facility that has only the front end portion of corrugated cardboard manufacturing cannot be accurately compared with a facility that has both front and back end corrugated cardboard operations. Currently there is no benchmarking data that has been performed for the corrugated cardboard industry.

CONCLUSIONS

There exist significant opportunities for energy consumption and cost savings in corrugated cardboard manufacturing facilities. Lighting, compressed air and motors are the major uses of electrical energy in these facilities. Consequently major electrical energy savings were identified in these areas. The steam heating system is the major natural gas energy usage due to significant steam usage in the manufacturing process. A combined heat and power system may be a good option for corrugated cardboard plants, which would generate significant energy cost savings. Based on our experiences at corrugated cardboard manufacturing facilities, there is a higher potential for energy efficiency opportunities in the front end of the manufacturing process compared to the back end.

Demand response opportunities can significantly reduce a plant's electrical energy costs if the plant is charged for electricity based on time-of-use. Demand response programs sponsored by certain utility companies can provide great incentives for facilities that can shed a portion of their electrical load during periods of extreme usage, which may result in cost savings of over thousands of dollars each year.

Although each plant has its own unique features, the measures identified in the paper can have applications in most plants.

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ACKNOWLEDGEMENTS

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TABLE 4 – SUMMARY OF SAVINGS AND COSTS AT A CORRUGATED CARDBOARD PLANT							
EEO No. Description		**Potential Energy Conserved**	**Demand Savings** (kW)	**Potential Savings** ($/yr)	**Resource Conserved**	**Implem. Cost** ($)	**Simple Payback** (years)
No or Very Low Cost Measures							
1 Repair Steam Leaks		35,149 therms/yr	N/A	19,400	Natural Gas	0	Immediate
2 Replace Standard Efficiency HID Lighting with High Efficiency HID Lighting		5,178 kWh/yr	1.31	1,694	Electricity	0	Immediate
3 Reduce the Air Compressor Discharge Pressure		15,905 kWh/yr	2.32	2,027	Electricity	70	Immediate
Low to Average Cost Measures							
4 Interlock the Chop-Out Knives with Their Cooling Fans		20,334 kWh/yr	2.96	2,591	Electricity	1,080	0.4
5 Use Photoelectric Sensors to Control the Shredders and Associated Blowers		240,771 kWh/yr	35.08	30,673	Electricity	2,415	0.1
6 Install an Automatic Blowdown System for the Steam Boiler		2,462 therms/yr	N/A	1,409	Natural Gas	4,710	3.3
7 Install Light Sensors and Bi-level Controllers on the HID Lamps in the Warehouse		14,880 kWh/yr	2.17	1,896	Electricity	5,836	3.1
8 Insulate the Steam and Condensate Return Pipes		7,655 therms/yr	N/A	4,382	Natural Gas	6,000	1.4
9 Insulate the Hot Plates		18,041 therms/yr	N/A	10,327	Natural Gas	7,000	0.7
Investment Grade Measures							
10 Replace HID Lighting with High Efficiency Fluorescent Lighting Throughout the Facility		101,724 kWh/yr	14.79	12,954	Electricity	22,024	1.7
11 Replace Air Pumps with Electric Viking Pumps		167,147 kWh/yr	24.35	21,294	Electricity	24,380	1.1
12 Install an Economizer to Preheat the Feedwater to the Steam Boiler		31,616 therms/yr	N/A	18,097	Natural Gas	30,000	1.7
Total Energy Savings	**(Electricity)**	**565,939 kWh/yr**					
	(Natural Gas)	**94,923 therms/yr**					
Total Demand Savings			**83.0 kW**				
Total Cost Savings				**$124,854/yr**			
Total Implementation Cost						**$103,515**	
Simple Payback Period							**0.8 years**