Energy Efficiency at Gostomel:

Recommendations and Energy Audit Report for Gostomel Glass Plant

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ENERGY EFFICIENCY AT GOSTOMEL: RECOMMENDATIONS AND ENERGY AUDIT REPORT FOR GOSTOMEL GLASS PLANT

Prepared with support from the U.S. Department of Energy
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Executive Summary

Gostomel Glass Plant produces bottles for beverages, perfumes and pharmaceuticals. Its customers include Coca-Cola, Pepsi Cola, Obolon (a large Ukrainian brewery) and several Ukrainian cosmetic and pharmaceutical companies. Gostomel's plant is located in the Kiev oblast, 16 miles from Kiev. In 1996, Gostomel had sales of 38.4 million hryvnia (approximately $21 million) and operating profit of 6.8 million hryvnia (approximately $3.8 million); about 20% of these sales were exports. The plant has run continuously at full capacity in recent years. Much of this success can be attributed to Gostomel's creative, market-oriented management. The company was privatized in 1993.

Gostomel's management and board of directors realize that the plant uses energy very inefficiently in comparison to similar plants in the West. This high energy use has created high costs. Gostomel management also knows that it could expand its market and sales if it could increase production capacity. Under a U.S. Department of Energy contract, the Pacific Northwest National Laboratory and the Ukrainian Agency for Rational Energy Use and Ecology (ARENA-ECO) have been collaborating with Gostomel with the goal of increasing energy efficiency at the plant. PNNL and ARENA-ECO have conducted a detailed energy audit of Gostomel, the findings of which are presented in this report.

The most significant energy efficiency measure considered was replacing glass furnace number 3 with a new, western furnace. This measure will produce large energy savings and will also allow Gostomel to increase the volume and quality of its production. The energy savings alone will not pay for the furnace, as indicated in the chart below. Nonetheless, the total benefits of the new furnace will likely make it a very appealing investment. We would also recommend:

- installing a high-efficiency compressed air system, including several new compressors, an automatic control system and a refrigerated air dryer system;
- installing heat recovery hot water boilers in the glass furnace exhaust system and a new hot water boiler;
- upgrading heat insulation on the hot water distribution system; and
- relocating the air intake for screw-type air compressors to outside the compressor building.

The table below summarizes the results of the energy audit and lists the proposed energy-efficiency and cost-reduction measures identified to be potentially cost-effective for the Gostomel Glass Plant. Several options for certain measures were analyzed; the options highlighted with three asterisks (***) are those we would recommend. The section at the bottom of the table provides information on the total cost, savings and return of four of the recommended measures; the glass furnace is not included in this section as it is not meaningful to compare energy-efficiency measures and modernization measures on the basis of energy savings.

Table S.1. Summary of Energy-Efficiency and Cost-Reduction Measures
(Items highlighted indicate recommended measures which are included in the total.)

Measure	Energy Savings		Cost ($USD)	Savings ($USD/yr)	Payback (years)	IRR (%/yr)
1. Upgrade glass furnace 3***						
	Natural Gas*	7,985,000 m^3/yr	18,190,000	592,900	**	
	Electricity*	-1,745,128 kWh/yr				
2a. Install high-efficiency compressed-air system						
- Option A***	Electricity	4,846,562 kWh/yr	967,754	193,862	5.0	19.5%
- Option B	Electricity	3,841,522 kWh/yr	914,710	153,661	6.0	15.9%
2b. Install two high-efficiency air compressors						
	Electricity	1,460,213 kWh/yr	476,940	58,409	8.2	10.6%
2c. Install automatic sequencing and load control system on existing compressor system						
	Electricity	944,070 kWh/yr	82,100	37,763	2.2	44.9%
3a. Install heat recovery hot water boilers in glass furnace exhaust systems						
- Option A	Natural Gas	1,784,313 m^3/yr	431,700	148,100	2.9	34.2%
- Option B***	Natural Gas	1,884,282 m^3/yr	530,900	156,395	3.4	29.3%
3b. Install hot water boiler to replace steam boiler system						
	Natural Gas	347,000 m^3/yr	153,250	28,800	5.3	18.1%
4. Upgrade heat insulation on hot water distribution system***						
	Natural Gas	175,320 m^3/yr	39,070	14,550	2.7	25.1%
5. Relocate air intake for screw-type air compressors to outside the compressor building***						
	Electricity	53,248 kWh/yr	4,000	2,130	1.9	53.2%

Total all recommended energy saving measures and options						
2a Option A, 3a Option B, 4, and 5.	Natural Gas Electricity Total	2,059,602 m^3/yr 4,899,810 kWh/yr 86,651 GJ/yr	1,541,724	366,937	4.2	23.1%
Total energy reduction potential identified in all recommended energy saving measures and options						
Natural Gas	8.7%	Electricity	15.1%	Total energy reduction		9.5%

*Based on maximum production level
**We recommend this measure as a modernization project. It cannot be economically justified based on energy savings alone. As a result, the payback and IRR based on energy savings are not meaningful, so we have left these calculations out.
*** Notes energy measures we recommend

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Table 1. General Conversion Factors for Energy

To:	TJ	Gcal	Mtoe	MBtu	GWh	1000 m^3 natural gas
From:	multiply by:					
TJ	1	238.8459	2.3885×10^{-5}	947.8	0.2778	29.8557
Gcal	4.1868×10^{-3}	1	10^{-7}	3.968	1.163×10^{-3}	0.125
Mtoe	4.1868×10^{4}	10^{7}	1	3.968×10^{7}	11,630	1.25×10^{6}
MBtu	1.0551×10^{-3}	0.252	2.52×10^{-8}	1	2.931×10^{-4}	0.03150
GWh	3.6	860	8.6×10^{-5}	3412	1	0.4499
1000 m^3 natural gas[1]	.03349	8.000	8.000×10^{-7}	31.744	2.2224	1

[1]Based on the energy value of the natural gas from Russia and Kazakhstan which Gostomel uses

Introduction

The purpose of this energy audit report is to identify and recommend specific energy-efficiency and cost-reduction opportunities identified during the energy audit and site visits of the Gostomel Glass Plant. The report identifies several energy-efficiency measures (EEM) which are cost effective for the plant's management to consider. In some cases, the audit team identified alternative EEMs which may be considered by the management team.

These measures would likely be part of a larger modernization effort in which Gostomel is working with several Western partners. Certain measures which we propose may need to be modified to reflect changes which will take place in the plant during modernization. We are committed to making these changes if necessary and appropriate.

The report is divided into five main sections. The first section is this introduction. The second section provides a summary of historical energy consumption for Gostomel Glass Plant and a breakout of end-use energy consumption for both natural gas and electricity. The heart of the report is the third section, which contains the specific EEMs recommended and alternatives evaluated for management consideration. Included in the fourth section is a descriptive list of additionally recommended energy-efficiency practices. These recommended practices do not involve initial capital investment. Rather, they involve general operating practices and future equipment selection. While these recommendations will increase material or equipment costs in the future, they will lower energy costs, providing more significant savings. The last section provides a descriptive list of other energy efficiency measures which the audit team considered but did not find cost-effective at this time. These measures should be reevaluated in the future as energy costs or production levels change.

EEM 1 regards the glass production furnaces. Replacing or modernizing the glass production furnaces cannot be economically justified based solely on energy savings. Therefore, no specific energy measure is recommended. However, the enterprise is considering a plant modernization which will impact the glass furnaces and their energy efficiency. For this reason, the energy impact of the proposed modernization is evaluated and reported.

EEM 2 relates to the air compressor system. The audit team recommendation (EEM 2a, option A) involves purchasing and installing several new high-efficiency air compressors including a new automatic control system. This measure provides significant energy savings and a good rate of return. As an alternative to this specific recommendation, the audit report also evaluates the procurement and installation of several conventional efficiency air compressors including the automatic control system (EEM 2a, Option B). These two options are mutually exclusive; management can select either one of these two options but not both. Furthermore, the audit report evaluates two other alternatives to the air compressor system. EEM 2b involves installing 2 new high-efficiency air compressors. EEM 2b is a low-cost, mutually-exclusive, alternative to EEM 2a and is evaluated only because it has a lower initial cost. Because most of the energy

savings resulting from EEM 2a are attributed to the automatic control system, EEM 2c evaluates installing a similar control system to the existing air compressors. While the internal rate of return for the EEM 2c alternative is greater than that of EEM 2a, option A, it is not as highly recommended. This is primarily because it is unclear how compatible the automatic stop-start feature of the automatic control system will be with the existing air compressors. This would have to be evaluated as part of the engineering design of the new system modifications.

EEM 3 involves a heat recovery opportunity. The EEM evaluates recovering waste heat from the glass furnace exhaust gases and using it to supplement the district heating system. The audit team recommendation is EEM 3a, option B. This measure involves using heat recovery from each of the glass furnaces. It also includes converting the district heating boiler to a hot water system from a steam-based system. As a lower cost alternative, EEM 3a, option B, evaluates the heat recovery system while making no changes to the main boiler facility. While EEM 3a, option A, may have a better internal rate of return, the boiler will soon reach the end of its useful life and will need to be replaced. EEM 3a, option B, provides a new boiler for the system. Another alternative for management consideration is EEM 3b. This option evaluates the replacement of the steam boiler serving the district heating system. If the heat recovery measure is ruled out by management, this measure should be given serious consideration.

EEM 4 recommends upgrading the heat insulation on the district heating piping system. The existing insulation has seriously deteriorated. The audit team's recommendation is to replace the damaged insulation. Based on the visual inspection performed during the site visits, at least 20% of the total insulation is in need of replacement. However, a more specific and detailed inspection should be performed. A more detailed inspection may reveal that more insulation is damaged and in need of replacement.

The final recommended EEM also concerns the air compressor system. EEM 5 recommends extending the air compressor inlet piping on the screw-type air compressors to outside the air compressor building similar to the inlet piping on the reciprocating air compressors.

Table 2. Summary of Historical Energy Consumption

Month	Natural Gas		Electricity		Total
	1,000 m^3	GJ	1,000 kWh	GJ	GJ
Jan-96	2,178	72,937	2,742	9,871	27,295
Feb-96	2,058	68,918	2,656	9,562	26,026
Mar-96	2,190	73,339	2,664	9,590	27,110
Apr-96	1,803	60,379	2,468	8,885	23,309
May-96	1,812	60,680	2,697	9,709	24,205
Jun-96	1,678	56,193	2,718	9,785	23,209
Jul-96	1,951	65,335	2,719	9,788	25,396
Aug-96	1,898	63,560	2,920	10,512	25,696
Sep-96	1,934	64,766	2,519	9,068	24,540
Oct-96	2,090	69,990	2,678	9,641	26,361
Nov-96	1,958	65,570	2,904	10,454	26,118
Dec-96	2,083	69,756	2,838	10,217	26,881
Total	23,633	791,422	32,523	117,083	306,147

* Note: Assume natural gas heating value of 8,000 kcal/m^3 or 33.49 GJ/1000 m^3.

Figure 1. Electricity Consumption

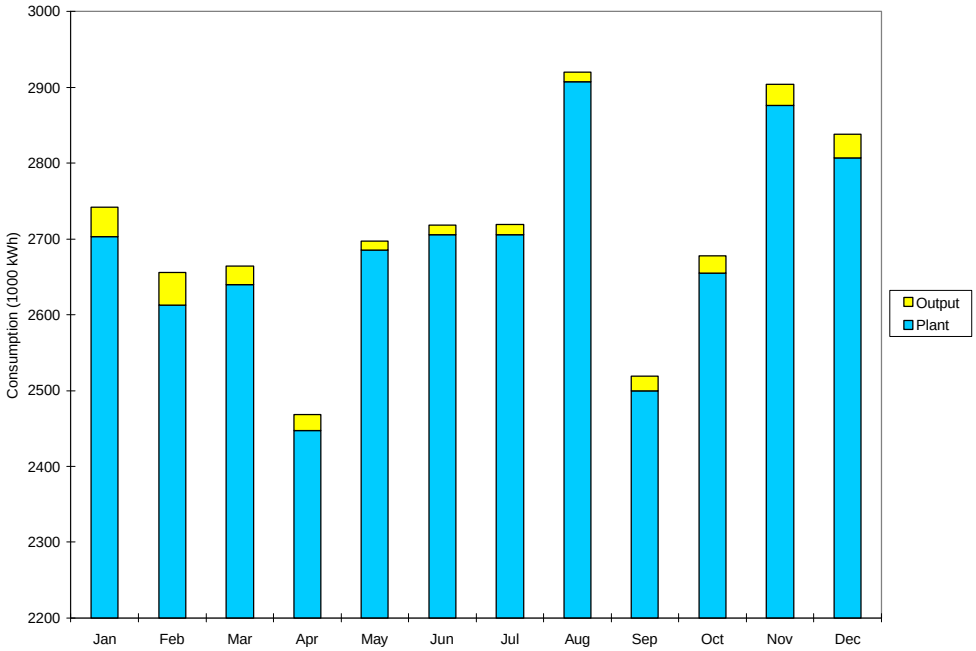


Figure 2. Natural Gas Consumption

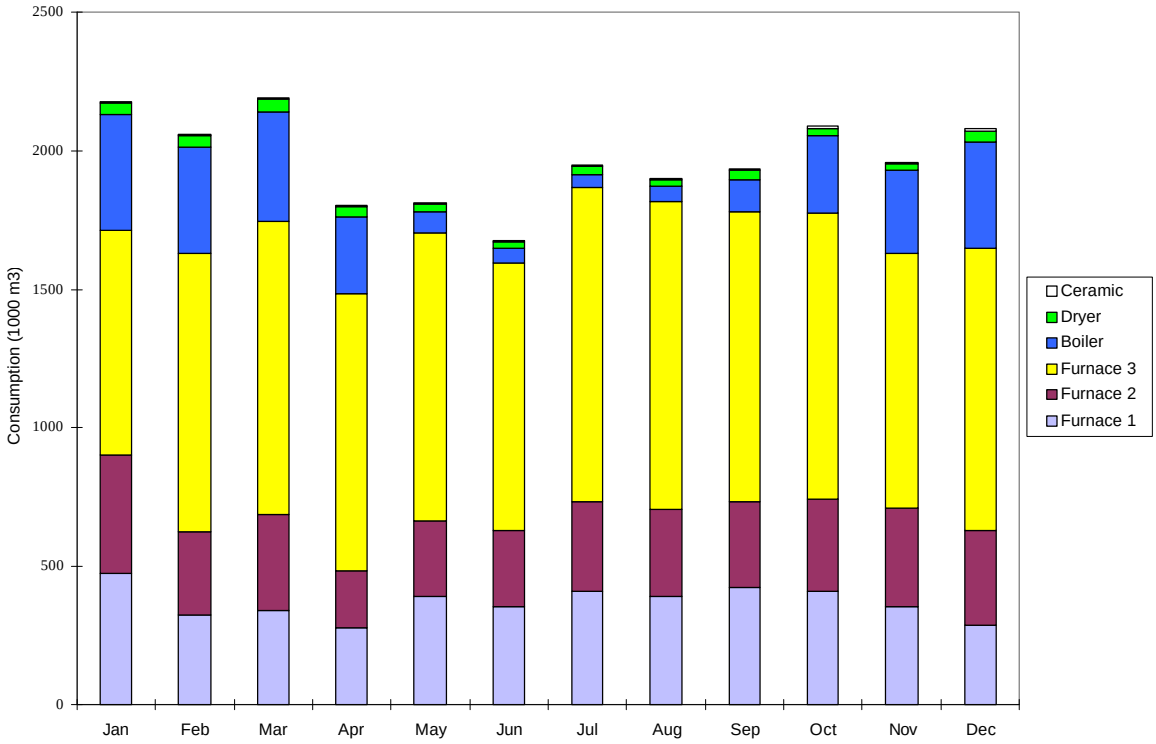


Figure 3. End-Use Electricity Consumption Distribution

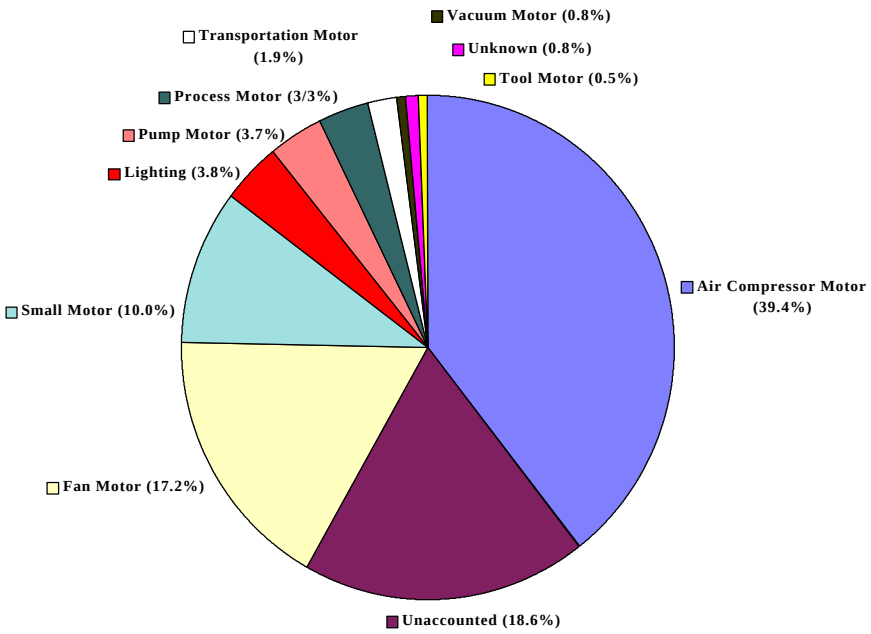
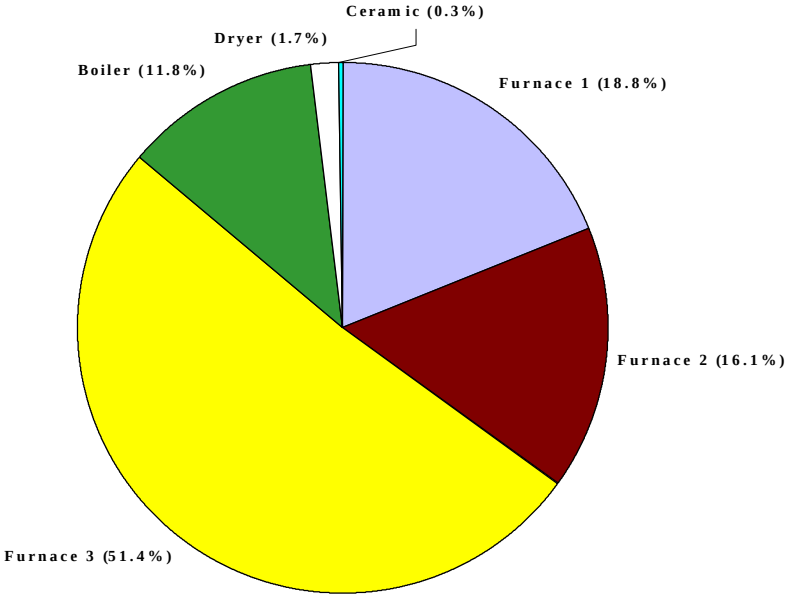


Figure 4. End-Use Natural Gas Consumption Distribution



Recommended Energy-Efficiency and Cost-Reduction Measures

The following energy-efficiency and cost-reduction measures are recommended and described in this section: upgraded glass furnaces; installation of a high-efficiency compressed air system, high-efficiency air compressors, an automatic sequencing and load control system on the current compressor system, a heat-recovery hot water boiler in glass-furnace exhaust systems, and a hot water boiler to replace the steam boiler; upgraded heat insulation on the hot water distribution system; and relocation of the air intake for screw-type air compressors from inside to outside the compressor building.

1. Upgrade glass furnaces

The largest energy consumers at the industrial enterprise are the three glass furnaces. The glass furnaces also hold the largest opportunity for energy savings at the enterprise. Unfortunately, as with many manufacturing processes, energy savings alone can not economically justify the replacement and upgrade of the glass furnaces. Energy savings, however, can sometimes justify incremental improvements to manufacturing equipment as they are replaced as part of a modernization process.

Gostomel is currently evaluating a proposal from a glass furnace company, Sorg, as part of a modernization of the enterprise manufacturing process. If constructed according to the specifications and recommendations of the glass furnace provider, the industrial enterprise will significantly reduce energy consumption in the production of glass. If not built according to the specifications and recommendations of the glass furnace provider, the new furnace may not reduce the energy consumption per unit of glass produced.

The existing glass furnace number 3 is the largest and most efficient of the three glass furnaces. In 1995, the unit produced 34,245 tonnes of glass product while consuming 10,784 thousand cubic meters of natural gas, according to a technical review report by Saint-Gobain. This can be summarized as an energy utilization index (EUI) of 2834 kcal/kg-glass (gas fuel only). The new furnace being proposed as part of the furnace modernization project is estimated to result in an EUI of 1220 kcal/kg-glass (gas fuel only), or 57% less natural gas fuel per unit of glass produced.

There are, however, several additional changes that also need to be addressed. The existing glass furnace does not use electric fans to supply combustion air to the process or to remove exhaust air from the furnace. Air movement through the existing furnace is by means of natural draft. The new furnace will use electric-motor-driven fans to supply air to the combustion process. This will allow for more precise control of the combustion process but will increase electricity consumption for the process. The new furnaces also use electric heaters to control the glass temperature in the forehearths whereas the existing furnaces use natural gas. While the new

furnaces will be able to control the glass temperature more precisely and improve glass quality, it will consume more electric energy. Electricity is more expensive per unit of energy than natural gas. Total additional electricity consumption will depend on glass production levels, and will likely range from about 1 to 1.7 million kWh per year.

One of the most important factors that could affect the energy consumption of the proposed new furnace is the selection of the furnace insulated firebrick. The existing glass furnaces have been constructed using inexpensive, low-quality firebrick. The result has been a short furnace life, significant heat loss and increased fuel consumption. The average life of the existing glass furnaces is approximately three years, after which time, the furnaces must be rebuilt. This is primarily because the furnace's firebrick thermally degrades. In addition to becoming structurally unsound, the degradation also results in an increasing heat loss through the furnace walls. During the site visit, the temperature of the furnace external walls were around 140 to 160°C for the one-year old furnace number 3 and around 300 to 400°C for the three-year old furnace number 1. In order to extend the life of the glass furnaces, Gostomel uses a series of electric-driven fans to supply cooling air to the external furnace walls. While this air supply does keep the furnace walls cooler and therefore extends the furnace life, it results in significant heat loss from the furnace which increases natural gas consumption and consumes additional electric energy.

For the modernization of furnace number 3, if a higher grade of insulated firebrick were selected, as the glass furnace manufacturer is recommending, the new life of the modernized furnace is estimated to be around 6 to 8 years. In addition, heat loss through the furnace walls will be significantly reduced and the cooling fans could be eliminated. Although the proposed higher grade firebrick is more expensive, it is highly recommended over the lower grade firebrick.

The new furnace being proposed is also significantly larger than the existing furnace. Furnace number 3 currently has a capacity of 53,500 tonne-glass per year. The new proposed furnace number 3 will have a maximum capacity of 79,350 tonne-glass per year. This is a 48% increase in furnace capacity. Assuming a 25% cullet rate, this implies that the new furnace will be able to produce 59,513 tonnes of glass per year. This is 11% greater than the total glass production of all three glass furnaces in 1995.

Based on the information provided in the preliminary proposal submitted by the glass furnace manufacturer, information from the technical review report generated by Saint-Gobain, and energy consumption data collected at the site during the audit visit, an estimate of the potential energy savings that could result from the proposed furnace modernization was calculated and is summarized below.

Summary of Results

Based on 1996 manufacturing production level:	30,838	Tonne/yr
Natural gas savings	5,172	1,000 m^3/yr
Electricity increase	973,650	kWh/yr
Cost reduction	$390,300	US dollars/yr
	702,600	hryvnia/yr
Based on maximum production level:	59,513	Tonne/yr
Natural gas savings	7,985	1,000 m^3/yr
Electricity increase	1,745,128	kWh/yr
Cost reduction	$592,900	US dollars/yr
	1,067,200	hryvnia/yr

2a. Install high-efficiency compressed-air system

This measure recommends installing new high-efficiency screw-type air compressors with an automatic sequencing and load control system. The existing air compressor system includes a mix of 10 reciprocating air compressors and 2 screw-type air compressors. The air compressors consist of a variety of capacities, manufacturers, and ages. The compressors are not efficient compared to equipment available today. Specifically, this measure recommends replacing the existing 10 reciprocating air compressors with four 260-kW (350 hp) water-cooled screw-type air compressors with refrigerated air dryers. A fifth unit could also be installed for reserve capacity, although this is optional. The existing low pressure reciprocating compressor should remain on-line and operated at full-load. In addition, the existing two 200-kW screw-type air compressors should remain but be operated only as reserve air compressors. In order to ensure adequate capacity, the other existing air compressors could also remain in the system, but should only be operated as emergency back-up compressors and not allowed to regularly operate in the system. The new air compressors specified will generate 12.28 m^3/kWh compared to the average existing air compressor's 10.16 m^3/kWh, an improvement of 20%. The useful life of the new compressors is estimated to be 20 years.

In the current compressed air system, compressor loads are controlled automatically by the individual air compressor control systems. The sequencing of compressors is accomplished manually: the operators are responsible for starting and stopping air compressors as the demand for compressed air increases or decreases. The mix of manual sequencing and individual load control results in inefficient operation of the air compressor system and allows the system-wide air pressure to fluctuate. Compressors operate most efficiently at, or near, full load. With manual sequencing, the load is evenly distributed across each of the operating compressors. This results in the compressors operating at partial load which is an efficient condition. With a central automatic sequencing and load control system, the load will be distributed such that most compressors operate near optimal load and one compressor operating at variable load to meet the

variable demand for compressed air. The control system will automatically bring additional compressors on-line as the demand for compressed air increases and take compressors off-line as the demand for compressed air decreases. The automatic sequencing and load control system identified for this measure is capable of controlling up to eight air compressors. In the future when the compressed air system is expanded as part of an overall expansion in manufacturing capacity, a larger automatic sequencing and load control system may need to be specified. Application of the automatic sequencing and load control system will reduce electricity consumption by an estimated 10%.

The control system will also improve the consistency of the air pressure in the distribution system. Under the present operating conditions system, pressure varies significantly, typically 5.0 to 6.25 bar. With the automatic sequencing and load control system, the distribution system pressure will be more constant.

Summary of Results

Option A

Electricity savings	4,846,562	kWh/yr
Cost reduction	$193,862	US dollars/yr
	348,952	hryvnia/yr
Implementation cost	$967,754	US dollars
	1,741,957	hryvnia
Internal rate of return	19.5 %	
Net present value at 20% over 20 years	-$19,800	US dollars
Simple payback	5.0	years

Data Assumptions

Electricity cost	$0.04	per kWh
Exchange rate ($1.00 USD)	1.8	hryvnia

Table 3. Existing Air Compressor System

Unit No.	Compressor Model Number	Air Output m^3/min	Rated Pressure bar	Motor Capacity kW	Compressor Efficiency m^3/kWh	Electric Energy kWh/yr
1-3	BP 20/8	50	8	300	10.00	3,808,000
4&10	2BM10-63/9	63	8	400	9.45	2,690,200
5&6	4BM10-100/8	100	8	630	9.52	4,144,800
7&8	BP20/8	20	8	130	9.23	468,000
9	2BM4-48/3	48	3	160	18.00	809,600
11-12	GA200/7.5	38	7	200	11.40	1,566,120
Net					10.16	13,486,720

Table 4. Proposed Air Compressor System, Option 2a

Unit No.	Compressor Model Number	Air Output m^3/min	Rated Pressure bar	Motor Capacity kW	Compressor Efficiency m^3/kWh	Electric Energy kWh/yr
Existing air compressors operated in reserve						
9	2BM4-48/3	48.0	3	160	18.00	766,885
11-12	GA200/7.5	38.0	7	200	11.40	391,304
New air compressors to be installed (Option A)						
13-16	SSR XFE350-2S	53.2	7.6	260	12.28	7,481,969
Net						8,640,158

Table 5. Alternative Air Compressor Options

Option	Unit No. or Quantity	Compressor Model Number	Air Output m^3/min	Rated Pressure bar	Motor Capacity kW	Compressor Efficiency m^3/kWh	Electric Energy kWh/yr	Energy Savings kWh/yr
Existing air compressors operated in reserve								
all	#9	2BM4-48/3	48	3	160	18.00	766,885	
all	#11&12	GA200/7.5	38	7	200	11.40	391,304	
New air compressors to be installed								
A	4	SSR XFE350-2S	53.2	7.6	260	12.28	7,481,969	4,846,562
B	5	SSR XF350	46.9	7.6	260	10.82	8,487,009	3,841,522
C	5	SSR XFE300-2S	46.5	7.6	225	12.40	7,407,706	4,920,325
D	5	SSR XFE300	42.9	7.6	225	11.44	8,029,332	4,299,200
E	4	SSR XFE400-2S	59.0	7.6	300	11.80	7,784,369	4,544,162

Implementation Cost

Compressor Option A

	Retail Cost	Total Cost
Model SSR XFE350-2S	4 @ $127,000	$508,000
Auto sequencing and load control system	1 @ $4,900	$4,900
Auto stop/start controls	7 @ $320	$2,240
Interface kits for new compressors	4 @ $455	$1,820
Interface kits for existing compressors	3 @ $455	$1,365
Oil removal filter system	4 @ $6,800	$27,200
Refrigerated air dryer system	4 @ $29,000	$116,000
Subtotal for equipment		***$661,525***
Installation labor		$75,000
Shipping and handling		$15,000
Customs		$117,000
Design and engineering (5% of equipment total)		$33,076
Contingency (10% of equipment total)		$ 66,153
Total Cost		***$967,754***

Compressor Option B

	Retail Cost	Total Cost
Model SSR XF350	5 @ $91,000	$455,000
Auto sequencing and load control system	1 @ $4,900	$4,900
Auto stop/start controls	8 @ $320	$2,560
Interface kits for new compressors	5 @ $455	$2,275
Interface kits for existing compressors	3 @ $455	$1,365
Oil removal filter system	5 @ $5,700	$28,500
Refrigerated air dryer system	5 @ $24,000	$120,000
Subtotal for equipment		***$614,600***
Installation labor		$85,000
Shipping and handling		$20,000
Customs		$102,920
Design and engineering (5% of equipment total)		$30,730
Contingency (10% of equipment total)		$ 61,460
Total Cost		***$ 914,710***

2b. Install two high-efficiency air compressors

This measure recommends installing two new high-efficiency screw-type air compressors. The existing air compressor system includes a mix of 10 reciprocating air compressors and 2 screw-type air compressors. The air compressors consist of a variety of capacities, manufacturers, and ages. The compressors are not efficient compared to equipment available today. Specifically, this measure recommends installing two new 260-kW (350 hp), water-cooled, screw-type air compressors with refrigerated air dryers.

The two new air compressors will be operated continuously and baseloaded. The new air compressors will be operated only at full load and not allowed to operate at partial load. By baseloading the new machines in this fashion, the most efficient compressors will operate the most, saving the most energy with the least investment. The existing air compressors will remain on-line and operated according to the current operating procedures. The new air compressors specified will generate 12.28 m^3/kWh compared to the average existing air compressor's 10.16 m^3/kWh, an improvement of 20%. The useful life of the new compressors is estimated to be 20 years.

This energy saving measure is an alternative to the previously discussed measure. The recommendations are mutually exclusive.

Table 6, below, shows data for the air compressor system proposed in option 2b.

Summary of Results		
Electricity savings	1,460,213	kWh/yr
Cost reduction	$58,409	US dollars/yr
	105,136	hryvnia/yr
Implementation cost	$476,940	US dollars
	858,492	hryvnia
Internal rate of return	10.6%	
Net present value at 20% over 20 years	-$160,400	US dollars
Simple payback	8.2	years
Data Assumptions		
Electricity cost	$0.04	per kWh
Exchange rate ($1.00 USD)	1.8	hryvnia
New compressor operation		
- Capacity	260	kW
- Air output (rated at 7.5 bar)	53.2	m^3/min
- Motor efficiency	95%	
- Average load	95%	
- Operating hours (average annual)	8,000	h/yr

Table 6. Proposed Air Compressor System, Option 2b

No. of Units	Compressor Model Number	Air Output m^3/min	Rated Pressure bar	Motor Capacity kW	Compressor Efficiency m^3/kWh	Electric Energy kWh/yr
Existing air compressors operated to meet actual air demand						
	Existing units				10.16	7,866,507
New air compressors to be installed						
2	SSR XFE350-2S	53.2	7.6	260	12.28	4,160,000
Net						12,026,507

Implementation Cost

	Retail Cost	Total Cost
Model SSR XFE350-2S	2 @ $127,000	$254,000
Oil removal filter system	2 @ $6,800	$13,600
Refrigerated air dryer system	2 @ $29,000	$58,000
Subtotal for equipment		***$325,600***
Installation labor		$37,500
Shipping and handling		$5,000
Customs		$60,000
Design and engineering (5% of equipment total)		$16,280
Contingency (10% of equipment total)		$32,560
Total Cost		***$476,940***

2c. Install automatic sequencing and load control system on existing compressor system

This measure recommends installing new automatic sequencing and load control system on the existing compressors. The existing air compressor system includes a mix of 10 reciprocating air compressors and 2 screw-type air compressors. In the current compressed air system, compressor loads are controlled automatically by the individual air compressor control systems. The sequencing of compressors is accomplished manually -- the operators are responsible for starting and stopping air compressors as the demand for compressed air increases or decreases. The mix of manual sequencing and individual load control results in the air compressor system operating inefficiently and allows the system-wide air pressure to fluctuate. Compressors operate most efficiently at, or near, full load. With manual sequencing, the load is evenly distributed across each of the operating compressors. This results in the compressors operating at partial load which is an efficient condition.

With a central automatic sequencing and load control system, the load will be distributed such that most compressors operate near optimal load and one compressor operating at variable load to meet the variable demand for compressed air. The control system will automatically bring additional compressors on-line as the demand for compressed air increases and take compressors off-line as the demand for compressed air decreases. The automatic sequencing and load control system necessary for this energy-efficiency measure will need to be capable of controlling all compressors on the system. Some custom design and programming may be necessary for implementation. Application of the automatic sequencing and load control system will typically reduce electricity consumption by 5 to 10%. In this case of applying a new control system to the existing compressors, it is estimated that energy consumption will be reduced 7%. The life of the new central control system is estimated to be around 10 years.

The control system will also improve the consistency of the air pressure in the distribution system. Under the present operating conditions system pressure varies significantly, typically 5.0 to 6.25 bar. With the automatic sequencing and load control system, the distribution system pressure will be more constant.

Summary of Results

Electricity savings	944,070	kWh/yr
Cost reduction	$37,763	US dollars/yr
	67,973	hryvnia/yr
Implementation cost	$82,100	US dollars
	147,780	hryvnia
Internal rate of return	44.9%	
Net present value at 20% over 10 years	$63,500	US dollars
Simple payback	2.2	years

Data Assumptions

Energy reduction (percent of existing consumption)	7%	
Electricity cost	$0.04	per kWh
Exchange rate ($1.00 USD)	1.8	hryvnia

Implementation Cost

Auto sequencing and load control system	$25,000
Auto stop/start controls 12 @ $500	$6,000
Interface kits for compressors 12 @ $500	$6,000
Subtotal for equipment	***$37,000***
Installation labor	$24,000
Shipping and handling	$2,500
Customs	$7,500
Design and engineering (15% of equipment total)	$5,550
Contingency (15% of equipment total)	$ 5,550
Total Cost	***$ 82,100***

3a. Install heat recovery hot water boilers in glass furnace exhaust systems

This measure recommends installing heat recovery boilers in each of the glass melting furnace exhaust systems for the purpose of preheating hot water currently generated by the central boiler plant. Recovering heat from the glass furnaces will reduce the load on the steam boiler system, thereby reducing the natural gas consumed by the boilers. Based on the potential heat recovery rates, there may be periods when the entire hot water demand may be satisfied through the heat recovery boilers. At least one steam boiler should remain active in order to assure meeting the total hot water demand. A simplified schematic of the proposed heat recovery system is illustrated in Figure 1.

The existing boiler system consumes natural gas and generates high pressure steam. There are two boilers; however, only one unit typically operates while the second unit is in cold standby. Steam pressure is typically around 6 bar. The steam is consumed in a shell-and-tube-style heat exchanger to generate hot water. The shell-and-tube-style heat exchanger is located in the boiler facility. The hot water is circulated through three parallel distribution loops that circulate throughout the Gostomel plant grounds, buildings, and some areas of the neighboring town. Hot water generated by the boiler system is used for typical domestic hot water requirements and for space heating during the winter season.

In addition to the installation of the heat recovery boilers, further energy savings will result from replacing the existing steam boilers with a new smaller hot water boiler. Installation of the waste heat recovery boilers will significantly reduce the load on the existing boilers. Also, hot water boilers inherently operate more efficiently than steam boilers. Hot water boilers do not require blowdown to maintain water quality as do steam boilers. Moreover, hot water boilers need less feedwater chemical treatment than steam boilers. A small hot water boiler will also be safer to operate than high pressure steam boilers.

The existing steam boilers should remain in place to act as back up, or reserve, boilers. This will allow the existing boiler to be started and brought on-line in such case as the heat recovery boilers or new small hot water boiler are down for maintenance and repair. A simplified schematic of how the new heat recovery boilers will be integrated into the hot water distribution system is shown in Figure 5. Figure 6 illustrates the optional hot water boiler in the system. The useful life of the new heat recovery system is estimated to be at least 20 years.

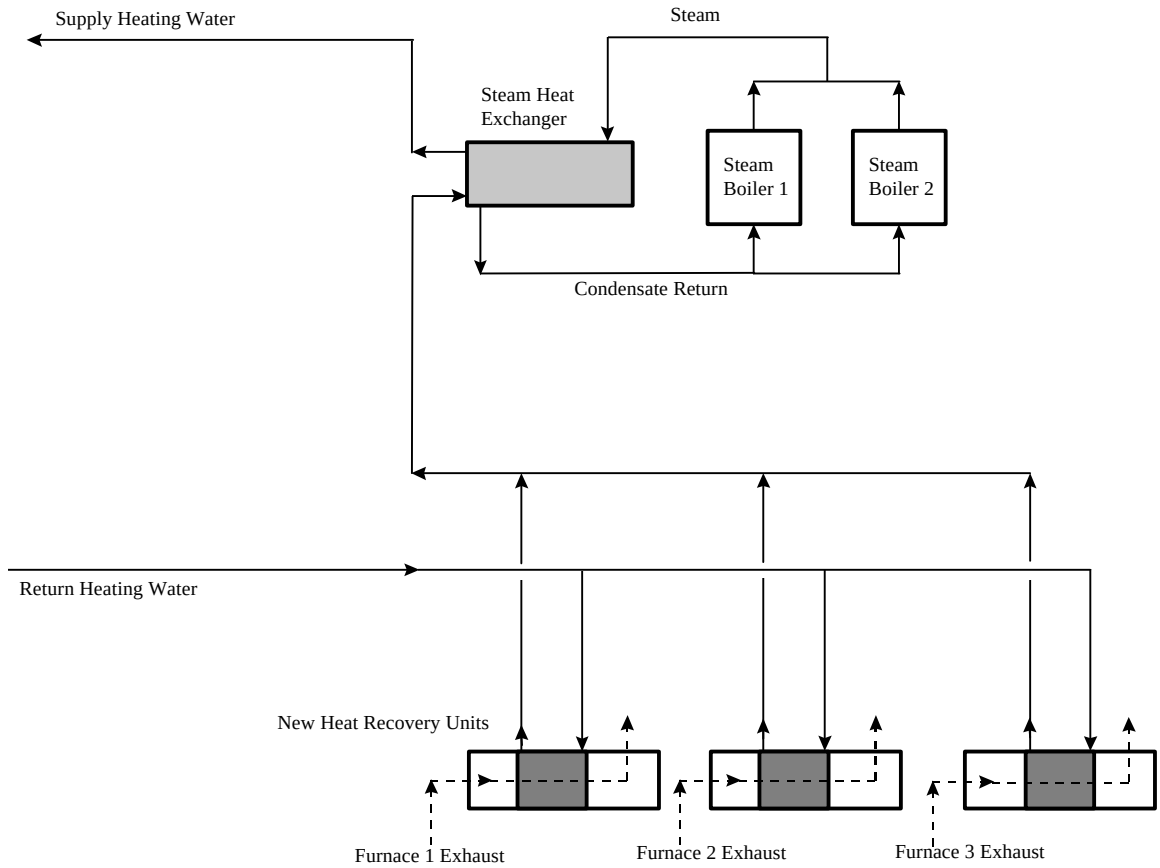


Figure 5. Option A - Heat Recovery from Glass Furnace Exhaust Systems

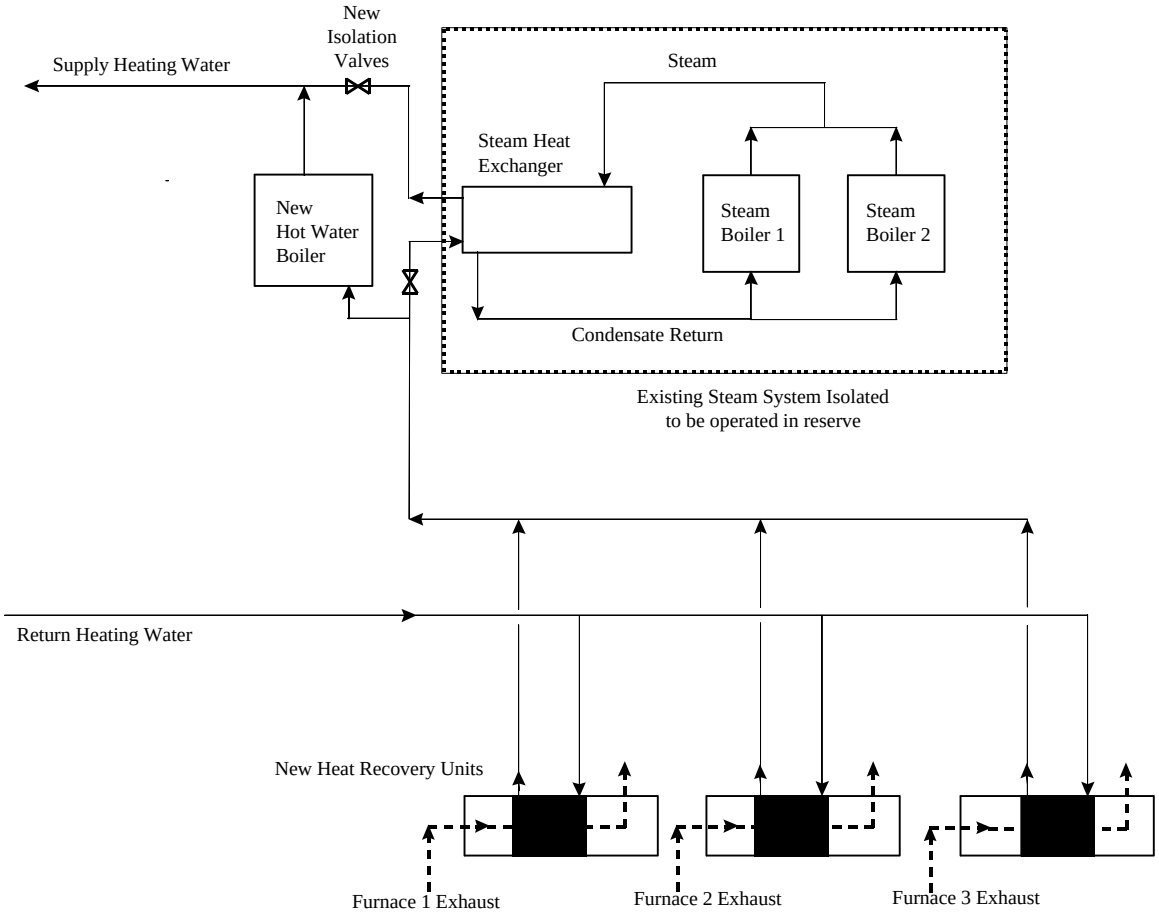


Figure 6. Option B - Heat Recovery with New Hot Water Boiler

Summary of Results

Heat Recovery Boilers

Natural gas savings	1,784,313	m^3/yr
Cost reduction	$148,100	US dollars/yr
	266,580	hryvnia/yr
Implementation cost	$431,700	US dollars
	770,060	hryvnia
Internal rate of return	34.2%	
Net present value at 20% over 20 years	$241,200	US dollars
Simple payback	2.9	years

Option: Heat Recovery Boilers with Hot Water Boiler

Natural gas savings	1,884,282	m^3/yr
Cost reduction	$156,395	US dollars/yr
	281,512	hryvnia/yr
Implementation cost	$530,900	US dollars
	955,620	hryvnia
Internal rate of return	29.3%	
Net present value at 20% over 20 years	$192,200	US dollars
Simple payback	3.4	years

Data Assumptions

Natural gas cost	$83	per 1,000 m^3
Exchange rate ($1.00 USD)	1.8	hryvnia
Existing furnace energy consumption		
- Furnace number 1	12,139,000	m^3/yr
- Furnace number 2	3,803,000	m^3/yr
- Furnace number 3	4,438,000	m^3/yr
Furnace operation:		
- Furnace number 1	8,760	h/yr
- Furnace number 2	8,760	h/yr
- Furnace number 3	8,760	h/yr
- Furnace reconstruction time occurs every 3 to 4 years		

Furnace exhaust gas temperature		
- Typical furnace operation	300 to 350	°C
- Minimum acceptable to prevent acid condensation	150	°C
Steam boiler data		
- Number of steam boilers (1 reserve)	2	Units
- Peak boiler capacity (each)	7.5	tonne/h
@ 80% efficiency and 440 kg-cal/kg-steam		
- Peak boiler consumption	550	m^3/h
- Steam pressure	6	bar
- Combustion efficiency (tested)	84%	
- Thermal efficiency (estimated)	70%	
- Natural gas consumption	2,784,000	m^3/yr
- Operation	8,760	h/yr
- Typical boiler blowdown rate	5%	
Heating hot water data		
- Total flow rate (metered)	350	m^3/h
- Number of hot water distribution loops	3	

Implementation Cost

Heat recovery boiler	
- Furnace 1	$128,000
- Furnace 2	$48,000
- Furnace 3	$48,000
Piping, valves, and insulation	$10,000
Controls	$19,000
Subtotal for equipment	***$253,000***
Installation labor (heat exchangers)	$70,000
Installation labor (distribution piping)	$7,500
Shipping and handling	$5,000
Customs	$45,600
Design and engineering (5% of equipment total)	$12,650
Contingency (15% of equipment total)	$37,950
Total Cost	***$431,700***

Additional Implementation Cost - Hot Water Boiler Option

Hot water boiler (high efficiency)	$61,000
Piping, valves, and insulation	$1,000
Subtotal for equipment	***$62,000***
Installation labor	$15,500
Shipping and handling	$5,000
Customs	$7,400
Design and engineering (5% of equipment total)	$3,100
Contingency (10% of equipment total)	$6,200
Total Additional Cost	***$99,200***

3b. Install hot water boiler to replace steam boiler system

This measure recommends converting the existing steam boiler system to a hot water boiler system. Converting from a steam-based system to a hot water system will allow the boiler system to operate more efficient by reducing sources of heat loss.

The existing boiler system consumes natural gas and generates high pressure steam. There are two boilers, however, only one unit typically operates while the second unit is in cold standby. Steam pressure is typically around 6 bar. The steam is consumed in a shell-and-tube-style heat exchanger to generate hot water. No steam is used outside of the boiler facility. The shell-and-tube-style heat exchanger is located in the boiler facility. The hot water is circulated through three parallel distribution loops that circulate throughout the Gostomel plant grounds, buildings, and some areas of the neighboring town. Hot water generated is used for typical domestic hot water requirements and for space heating during the winter season.

A conventional steam boiler has certain inherent losses. First, it operates at higher temperatures. Because of the higher temperatures, there are greater thermal losses in the steam distribution lines. Second, as the high pressure condensate departs from the shell-and-tube heat exchanger and returns to the boiler feedwater tank, a certain amount of the condensate flashes to steam and is lost from the system. Third, because of this flash steam loss, make-up water has to be added to the feedwater. The make-up water must be chemically treated more than the condensate returned. Fourth, make-up water introduces impurities to the steam system that must be periodically purged in the form of blowdown from the boiler drum. The greater the level of impurities, the greater the amount of blowdown required. Blowdown carries away the impurities, but it also wastes considerable energy, water, and chemicals.

Converting the boiler system to hot water and eliminating the steam cycle, will reduce the operating temperatures, eliminate the flash steam loss, significantly reduce the amount of chemical

treatment required and eliminate the requirement for blowdown. The life of the proposed hot water boiler is between 25 and 30 years. A life of 20 years was used in the economic calculations.

To reduce the implementation cost, the existing boilers should remain installed and operated in reserve in case the new hot water boiler is down for maintenance or repair. If possible, the existing steam boilers should be converted to hot water from steam. A qualified engineering team should evaluate the existing boilers to determine if it is possible to convert them to hot water.

Summary of Results		
Natural gas savings	347,000	m^3/yr
Cost reduction	$28,800	US dollars/yr
	51,840	hryvnia/yr
Implementation cost	$153,250	US dollars
	275,850	hryvnia
Internal rate of return	18.1%	
Net present value at 20% over 20 years	-$10,800	US dollars
Simple payback	5.3	years
Data Assumptions		
Natural gas cost	$83	per 1,000 m^3
Exchange rate ($1.00 USD)	1.8	hryvnia
Steam boiler data		
- Number of steam boilers (1 reserve)	2	Units
- Peak boiler capacity (each)	7.5	tonne/h
@ 80% efficiency and 440 kg-cal/kg-steam		
- Peak boiler consumption	550	m^3/h
- Steam pressure	6	bar
- Combustion efficiency (tested)	84%	
- Thermal efficiency (estimated)	70%	
- Natural gas consumption	2,784,000	m^3/yr
- Operation	8,760	h/yr
- Typical boiler blowdown rate	5%	
Proposed hot water boiler data		
- Peak capacity (output)	3.3	Gcal/h
- Combustion efficiency (minimum, based on fuel higher heating value)	84%	
Implementation Cost		
Hot water boiler (high efficiency)	$100,000	

Piping, valves, and insulation	$5,000
Subtotal for equipment	***$105,000***
Installation labor	$27,500
Shipping and handling	$5,000
Customs (should be able to purchase in Ukraine)	0
Design and engineering (5% of equipment total)	$5,250
Contingency (10% of equipment total)	$10,500
Total Additional Cost	***$153,250***

4. Upgrade heat insulation on hot water distribution system

This measure recommends replacing damaged heat insulation on the hot water distribution piping system. An inspection of the heat insulation on the hot water distribution piping system revealed significant damage. Damaged or wet insulation results in greater heat loss. The result of this heat loss is a lowering of water temperature in the heating system, making it less effective for space heating, and an increase in the heat load on the boiler. Replacing the damaged sections of the heat insulation will reduce the load on the boiler, thereby saving energy.

The estimated life of the heat insulation is about 5 years. The life of heat insulation is a function of the abuse the insulation receives and the type of protective covering, but it is also a function of the quality of installation. The better the quality of installation, the longer the insulation will last.

During the energy audit site visit, the quality of the existing insulation was visually examined. A visual inspection is not sufficient to identify the extent of the damaged insulation. It is recommended that the entire hot water distribution system be inspected with infrared thermography in order to identify the damaged sections of heat insulation that need to be replaced. For purposes of this energy-efficiency measure, it is assumed that 20% of the heat insulation is damaged and needs to be replaced. It is possible that a greater amount is severely damaged, making the potential energy savings even greater. The infrared inspection service may be rented and is included in the implementation cost estimate. It is also recommended that the enterprise use the infrared thermography service to inspect the glass furnace structures and inside the major electrical service panels during the same visit. The infrared thermography inspection service may identify additional areas to reduce energy loss.

Summary of Results

Assuming 20% of insulation is replaced		
Natural gas savings	173,320	m^3/yr
Cost reduction	$14,550	US dollars/yr
	26,190	hryvnia/yr
Implementation cost	$39,070	US dollars
	70,326	hryvnia
Internal rate of return	25.1%	
Net present value at 20% over 5 years	$3,700	US dollars
Simple payback	2.7	years

Data Assumptions

Natural gas cost	$83	per 1,000 m^3
Hot water supply temperature (typical)	66	°C
Existing insulation qualities		
- Insulation type:	Mineral wool	
- Thickness (all pipe sizes)	30	mm
- Effectiveness	80%	
(Assumes 20% of insulation is ineffective due to damage)		
Proposed insulation qualities		
- Insulation type:	Closed cell, high working temperature, 0 water vapor transmission	
- Thermal conductivity (kcal-mm/h-°C-m^2)	31	
- Outer cover material:	Heavy-duty, all-weather jacket and sealant	
- Thickness recommended:		
• 200 mm and 150 mm pipes	80	mm
• all other pipe diameters	50	mm

Table 7. Weather Data (Mean)

Temperature Bin Data			
High (°C)	Low (°C)	Average (°C)	Occurrence (hours/yr)
35.0	32.2	33.6	3
32.2	29.4	30.8	34
29.4	26.7	28.1	163
26.7	23.9	25.3	269
23.9	21.1	22.5	473
21.1	18.3	19.7	760
18.3	15.6	16.9	858
15.6	12.8	14.2	871
12.8	10.1	11.4	654
10.1	7.2	8.6	639
7.2	4.4	5.8	579

Temperature Bin Data			
High (°C)	Low (°C)	Average (°C)	Occurrence (hours/yr)
4.4	1.7	3.1	868
1.7	-1.1	0.3	1071
-1.1	-3.9	-2.5	608
-3.9	-6.7	-5.3	360
-6.7	-9.4	-8.1	229
-9.4	-12.2	-10.8	132
-12.2	-15.0	-13.6	96
-15.0	-17.8	-16.4	42
-17.8	-20.6	-19.2	31
-20.6	-23.3	-21.9	11
-23.3	-26.1	-24.7	9

Table 8. Distribution Piping Sizes and Lengths (Entire System)

Diameter (mm)	Length (meters)
200	384
150	452
125	256
100	490

Diameter (mm)	Length (meters)
80	540
70	42
50	712
40	10

Diameter (mm)	Length (meters)
32	4
25	214
20	6

Implementation Cost

Assuming 100% of insulation is replaced	
Insulation	$80,925
Installation labor	$66,570
Infrared thermography inspection	$5,000
Shipping, handling, and customs (5% of material cost)	$4,045
Design and engineering (5% of material)	$4,045
Contingency (10% of material and labor)	$14,750
Total Cost	***$175,335***

Assuming 20% of insulation is replaced	
Insulation	$16,185
Installation labor	$13,315
Infrared thermography inspection	$5,000
Shipping, handling, and customs (5% of material cost)	$810
Design and engineering (5% of material)	$810
Contingency (10% of material and labor)	$2,950
Total Cost	***$39,070***

5. Relocate air intake for screw-type air compressors to outside the compressor building

This energy-efficiency measure recommends modifying the air intake on the two rotary-screw type air compressors in order to extend the air intake to outside the central air compressor building. The existing air intake vents are located within the insulated housing of the rotary screw air compressors. Although the compressor housings are ventilated, the air temperature in the vicinity of the air intake is extremely hot. Warm air requires more power and energy to compress than cool air as noted in the table below. By extending the air intake to outside the central air compressor building, cooler air will be provided at the inlet requiring less energy to compress.

To implement this energy-efficiency measure, the intake filters should be removed and an oversized pipeline installed from the compressor intake to outside the compressor building. The compressor intake filter should then be re-installed at the new air inlet. It would also be beneficial to insulate the new inlet pipe to minimize heat gain in the compressor building. An oversized pipeline is installed in order to ensure that the new extended intake line does not cause excessive pressure drop entering the compressor. Extending the intake line to outside the compressor building will ensure the coolest air source for the compressed air system. The life of this energy-efficiency measure is assumed to be 20 years.

It was noted during the site visit that most of the existing reciprocating air compressors already had intake lines installed outside the compressor building. However, for those compressors that still have their air intake located near the compressor, this same procedure should be installed. Care should also be taken to clean the intake filters often. Dirty air filters will result in an increase pressure drop at the air compressor inlet which will lower compressor efficiency. Intake filters located outside may need to be cleaned more frequently.

Summary of Results

Electricity savings	53,248	kWh/yr
Cost reduction	$2,130	US dollars/yr
	3,834	hryvnia/yr
Implementation cost	$4,000	US dollars
	7,200	hryvnia
Internal rate of return	53.2%	
Net present value at 20% over 20 years	$5,300	US dollars
Simple payback	1.9	years

Data Assumptions

Electricity cost	$0.04	/kWh
Estimated average reduction in inlet air temperature	10	°C
Existing electrical consumption of screw-type air compressors	1,566,120	kWh/yr

Implementation Cost

Piping	$1,275
Installation labor	$1,825
Shipping and handling	$130
Customs	0
Design and engineering (10% of equipment and labor)	$310
Contingency (15%)	$460
Total Cost	***$4,000***

Table 9. Compressed-Air Data

Inlet Air Temperature (°C)	Air Flow Rate (m^3/min)	Power Savings (% kW)
0	93.2	6.8%
5	94.9	5.1%
10	96.6	3.4%
15	98.3	1.7%
20	100.0	Baseline
25	101.7	-1.7%
30	103.4	-3.4%
35	105.1	-5.1%
40	106.8	-6.8%
45	108.5	-8.5%
50	110.2	-10.2%

Note: Baseline temperature 20°C.

Additional Recommended Energy-Efficiency Practices

This section discusses additional energy-efficiency measures that are recommended. However because of the lack of available data, accurate estimates of the potential energy savings could not be determined. These energy-efficiency measures, however, are usually low-cost or maintenance-related practices that are typically cost effective providing excellent economic returns.

6. Identify and repair leaks in the compressed-air system: Leakage in compressed air distribution systems are expensive and should be repaired as soon as they are identified. The table below may be used to estimate the energy wasted by compressed air leaks. While it is impossible to eliminate all leaks, it is important to minimize leakage. It is recommended that the enterprise perform regular inspections of the compressed air distribution system in order to identify and repair any leaks. To assist in identifying compressed air leaks in noisy manufacturing areas, it is helpful to have an ultrasonic leak detector. Ultrasonic leak detectors amplify the sound generated by pressure leaks but filter out other sounds. This makes identifying compressed air leaks easy even is extremely noisy environments. Ultrasonic leak detectors are available from several companies with costs that vary from around $500 up to $2,000 U.S. dollars.

Energy audits and surveys of manufacturing industry in the United States have shown that losses in compressed air systems through leaks can typically account for around 25% of the total energy consumption of the air compressors. An active maintenance program to identify and repair compressed-air leaks could reduce the typical loss through leaks to around 10%. Although the audit team feels that leaks are not severe at this facility, such a reduction would save approximately 2,247,786 kWh/yr at a value of $89,911/yr (U.S. dollars).

Table 10. Energy Loss Through Compressed Air Leaks, kWh/yr

Leak Diameter (mm)	Air Pressure			
	6 bar	5 bar	3 bar	2.5 bar
10	152,468	139,184	107,811	98,418
7.5	85,763	78,291	60,644	55,360
5	38,117	34,796	26,953	24,604
2	6,019	5,567	4,312	3,937
1	1,525	1,392	1,078	984

Note: Energy loss is based on a nozzle coefficient of 60%, a compressor efficiency of 10.16 m^3/kWh, and a motor efficiency of 95%.

Excessive leaks in the compressed air distribution system also result in increase flow through the pipes which in turn increases the pressure drop through the distribution system. By repairing

excessive leaks, the pressure drop through the distribution system will be reduced. This may allow the plant to reduce the pressure set point at the main compressor station, thereby saving additional energy.

7. Operate compressors at lowest acceptable air pressure: While it is important to have adequate pressure in the compressed air distribution system to operate pneumatic equipment in the manufacturing production area, excessive pressure wastes energy. It is recommended that the enterprise investigate whether the air pressure set points in the central air compressor plant can be lowered while still providing adequate pressure at the points of use. Figure 7 below illustrates the potential energy savings by reducing the pressure at the compressors.

The industrial enterprise operates two compressed air distribution systems. The high pressure system is specified to operate at 6 bar while the low pressure system is specified to operate at 3 bar. In practice, according to the recording pressure chart located in the central compressor plant, the high pressure system actually operates at between 5.0 and 6.25 bar. The low pressure system does not have a recording pressure chart, however, the schematic drawing of the compressed air distribution system identifies the low pressure system as 2.5 bar. These two observations illustrate that it may be possible to reduce the operating pressure of the two compressed air distribution systems.

To demonstrate the potential for energy savings, if the high pressure compressed air distribution system could be reset from 6 bar to 5 bar, energy consumption would be reduced by approximately 8%. If the low pressure compressed air distribution system could be reset from 3 bar to 2.5 bar, energy consumption could be reduced by approximately 4%. In order to accomplish this pressure reduction, it may be necessary to increase the size of the compressed air receiver tanks.

Another method to accomplish this energy-efficiency measure is to generate enough air for the 3-bar distribution system so that no air from the 6-bar distribution system is required to feed into the 3-bar system through the existing pressure reducing valves. Generating compressed air directly at 3-bar instead of generating compressed air at 6-bar and then reducing the compressed air to 3-bar would require around 23% less energy. Generating compressed air at 6-bar and then feeding it to the 3-bar distribution system wastes considerable energy.

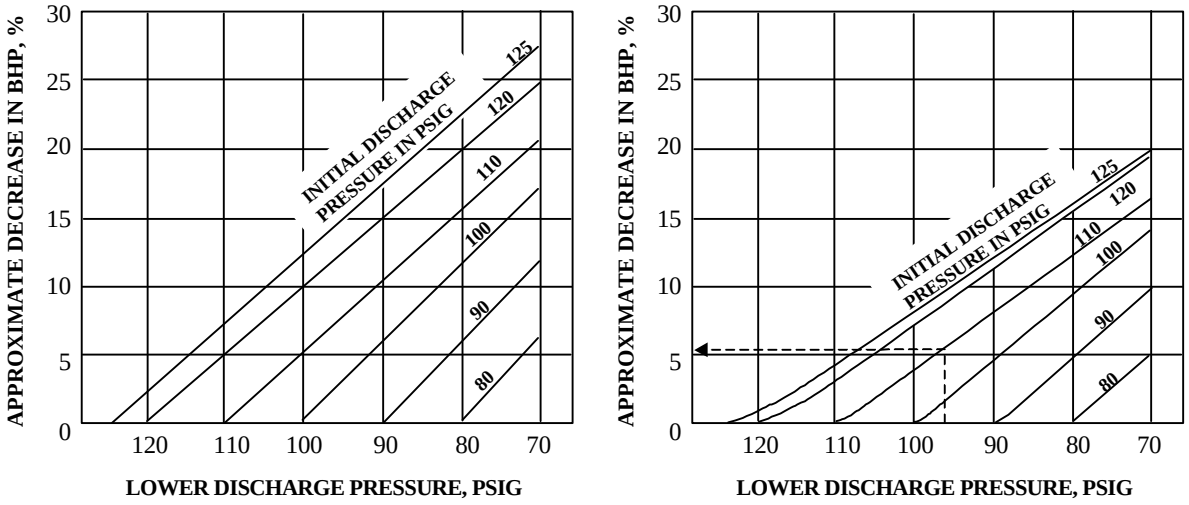


Figure 7. Relationship Between Discharge Pressure and Power in Air Compressors
Power reduction from reducing air pressure set point (left) single-stage reciprocating and rotary-screw compressors, (right) two-stage reciprocating and centrifugal compressors, (U.S. Department of Commerce, 1974).

8. Install properly-sized motors: During the energy audit site visit, electric power loads were tested on several motors. The results of the tests identified several motors that are significantly oversized. Downsizing these motors to more appropriate sizes will save energy. Motor efficiency improves when the motor is closer to fully loaded. Efficiency drops considerably when the motor is oversized.

Oversizing motors results in a increased first cost, because larger motors are more expensive than smaller motors, and oversizing motors also results in increased operating costs, because oversized motors operate less efficient than properly sized motors. In addition, motor life is reduced when motors are significantly oversized. Oversized motors tend to operate at hotter temperatures than properly sized motors and this reduces motor life.

It is recommended that the enterprise perform electric load tests on motors, such as fans and pumps, and consider downsizing motors found to be less than 50% loaded. A properly sized motor should be loaded between 75% and 100% of full load.

9. Tighten and align motor belt drives: During the energy audit site visit, the audit team noticed that some belt drives were not properly tightened. While belt drives are a cheap and efficient energy transmission system, belt drives do require proper maintenance in order to remain efficient. It is recommended that belt drives systems be checked for proper belt tension and for proper alignment. Loose belts and misaligned belt drives result in increased slippage and increased friction losses. The increased losses result in additional electricity consumption and reduced belt life. Applying proper belt tension and keeping belt drives properly aligned will

reduce motor loads, resulting in electricity savings and, in some cases, increased belt life. Training staff responsible for motor and motor drive systems is also recommended.

Energy-Efficiency Measures Considered but Not Recommended

During the initial site visit, the audit team identified several potential energy-efficiency measures believed to be applicable to the industrial enterprise. On further investigation, it has been determined that some of these initial energy-efficiency measures should not be recommended at this time. For the most part, these initial energy-efficiency measures have been found to be either not cost effective or not feasible at this time. These energy-efficiency measures should not be totally discounted. In the future, factors may change making these potential energy-efficiency measures more appropriate for consideration. These initial energy-efficiency measures are identified below.

- **Specify and install premium-efficiency and high-efficiency motors.** Motors consume the majority of electric energy in any industry. Therefore, motor efficiency is very important and is a significant source of potential energy savings. In the United States two new motor classes have emerged: energy-efficient motors and premium-efficiency motors. Energy-efficient motors are typically around 2% to 5% more efficient than standard-efficiency industrial motors. Premium-efficiency motors are typically around 5% to 10% more efficient than standard-efficiency industrial motors. These two new motor classes, however, do not always cost more than standard-efficiency industrial motors. Considerable time was spent contacting motor vendors in the European market. At this time, no manufacturer of motors for the 50-Hz market has been identified that makes energy-efficient or premium-efficiency motors. When this market barrier is corrected, this energy-efficiency measure will hold very significant energy-saving potential for Gostomel.

- **Switch to a multi-tariff billing system.** The energy audit team analyzed the cost-effectiveness of switching to a multi-tariff billing system for electricity. The analysis was based on actual consumption of electricity during 24-hour periods in several seasons; such an analysis was possible because of new 3-phase ABB meters that Gostomel installed in May 1997. The metering data show that switching to a multi-tariff billing system without shifting a significant portion of electricity consumption from peak rate to off-peak rate times will lead to an increase in electricity costs of 8-15%. Such a shift, therefore, is not recommended at this time.

Most of the energy-consuming equipment at Gostomel operates with an even load 24 hours a day. The only sizeable opportunity to shift electricity consumption to non-peak rate periods is in the raw material storage and preparation shop. Raw material could be unloaded to the storage areas at night instead of during the day, which would lower the tariff rate for electricity consumed in this shop's pneumatic pumps and in the air compressor system. In addition, electricity consumed to prepare batches of raw materials and place them in the batch storage area could be shifted to middle-peak and off-peak periods, thereby reducing electricity consumption during peak hours.

These changes would reduce the electricity bill in the raw material storage and preparation shop by about $37,000 per year, which is the equivalent of about 3% of the total annual plant electricity bill. However, these savings will not be not sufficient to cover the increased electricity

costs (8-15%) at the rest of the plant. In other words, there are not enough opportunities to shift the electricity load at Gostomel to make multi-tariff billing cost-effective for this plant.

- **Install an automatic combustion control system in the steam boilers**. This energy-efficiency measure was determined to be not cost effective. A fully automatic combustion and trim control system for the steam boiler would cost $10,000 to $12,000 U.S. dollars. This control system would control the air-to-fuel ratio in the boiler in order to maximize combustion efficiency. Because of the existing feedwater economizer on the boiler and the current manual air-to-fuel ratio control practice, an automatic monitoring and control system would not save enough natural gas to economically justify the capital cost.

A combustion test was performed on the operating steam boiler. While operating at high load, the boiler was operating with 30% excess air. A well maintained boiler could operate with 10% excess air. However, the feedwater economizer reduced the exhaust stack temperature from 222°C to 112°C. A stack temperature of 112°C is considered rather low and is on the verge of causing condensation problems. The site, however, did not indicate that condensation of moisture in the exhaust gas was causing any problems. The burner appeared to be in good condition, as indicated from a low level of incomplete combustion. The amount of carbon monoxide (CO) in the exhaust gas was only 7 mg/m^3. Oxides of nitrogen (NO_x) were measured to be around 166 mg/m^3.

- **Install variable-speed drives on the boiler combustion air and exhaust air fan motors**. This energy-efficiency measure was determined to be not cost effective. Variable-speed drives are usually cost effective for motors with loads above 10 kW that operate more than 8000 hours per year. The load on the boiler fan motors was considerably below this limit.

- **Install variable-speed drives on the air compressor cooling water pump motors**. This energy-efficiency measure was determined to be not cost effective.

- **Preheat the combustion air for the raw material dryers using the exhaust gases**. This energy-efficiency measure was determined to be not technically or economically feasible. Because of the natural draft combustion system, the large amount of excess air, and resulting low exhaust gas temperature exiting the raw material dryers, this measure was not appropriate. If the raw material dryers used force-air combustion (supply fan), the measure would be technically feasible. However, because of the low temperature of the exhaust gases exiting the dryer, this measure is not likely to be cost effective. If the number of operating hours per year were increased, the cost of natural gas increased, or the relative cost of the heat exchanger were decreased, this energy-efficiency measure should be re-evaluated.

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Appendix 1: Electricity Consumers

Table A.1: Detailed List of Electricity Consuming Equipment

End-Use Category	Type	Qty.	Capacity kW	Efficiency	Load Factor	Operating Hours/Year	Demand kW	Energy (kW/Year)
Compressor Stations								
Motor: Air Compressor	2BM10-63/9	1	400	93.9%	73.2%	1,600	312.0	499,200
Motor: Air Compressor	2BM10-63/9	1	400	93.9%	73.5%	7,000	313.0	2,191,000
Motor: Air Compressor	4BM10-100/8	1	630	94.1%	70.4%	1,300	471.0	612,300
Motor: Air Compressor	4BM10-100/8	1	630	94.1%	70.4%	7,500	471.0	3,532,500
Motor: Air Compressor	BP-50/8	2	300	89.0%	66.5%	7,500	224.0	3,360,000
Motor: Air Compressor	BP-50/8	1	300	89.0%	66.5%	2,000	224.0	448,000
Motor: Air Compressor	BP-20/8	1	130	91.2%	54.7%	6,000	78	468,000
Motor: Air Compressor	BP-20/8	1	130	91.2%	66.6%	0	95	0
Motor: Air Compressor	GA-200-7,5	1	200	90.5%	56.5%	4,400	124.8	549,120
Motor: Air Compressor	GA-200-7,5	1	200	90.5%	76.7%	6,000	169.5	1,017,000
Motor: Air Compressor	2BM4-48/3	1	160	91.8%	105.6%	4,400	184.0	809,600
Pump Cold Water #1		1	16	87.5%			reserve	
Pump Cold Water #2	SF 100 L-4	1	22	88.5%	72.0%	8,760	17.9	156,804
Pump Cold Water #3		1	15	87.5%			reserve	
Pump Cold Water #4		1	11	85.5%			reserve	
Pump Hot Water #1	4A	1	46	90.2%	31.0%	8,760	15.8	138,408
Pump Hot Water #2		1	7	84.0%			reserve	
Pump Hot Water #3		1	16	87.5%			reserve	
Lighting			14		50.0%	4,000	7.0	28,000

End-Use Category	Type	Qty.	Capacity kW	Efficiency	Load Factor	Operating Hours/Year	Demand kW	Energy (kW/Year)
Raw Material Shops								
Process Line: Sand 1								
	B3	1	3	80.0%	50.0%	7,665	1.875	14,372
	4A	1	3	80.0%	50.0%	7,665	1.875	14,372
Elevator	4AM	1	7.5	84.0%	50.0%	7,665	4.4	34,219
Transporter	AUP	1	1.5	75.0%	50.0%	7,665	1	7,665
Driving Dry Drum Sand	AO	1	10	85.5%	50.0%	7,665	5.8	44,825
Crush		1	11	85.5%	50.0%	2,000	6.4	12,866
Transporter		3	4	82.0%	70.0%	2,000	3.4	20,488
Fan	4AM250M842	1	45	91.5%	70.0%	8,000	9.1	72,800
Elevator		1	11	85.5%	50.0%	1,000	6.4	6,433
Process Line: Sand 2								
Driving Dry Drum Sand	4A	1	11	85.5%	60.0%	7,300	4.9	35,770
Elevator Damp Sand		1	7.5	84.0%	70.0%	7,300	6.25	45,625
Elevator Damp Sand		1	5.5	84.0%	70.0%	7,300	4.58	33,458
Fan		1	30	88.5%	70.0%	7,300	23.7	17,3220
Process Line: Dolomite								
Crush	AO	1	40	90.2%	10.4%	7,300	4.6	33,580
Driving Dry Drum Dolomite		1	7.5	84.0%	16.8%	7,300	1.5	10,950
Elevator	4A	1	7.5	84.0%	50.0%	7,300	4.4	32,589
Driving Mill Dolomite		1	55	88.0%	62.7%	7,300	39.2	286,160
Elevator Dry Dolomite	4A	1	7.5	84.0%	70.0%	7,300	6.25	45,625

End-Use Category	Type	Qty.	Capacity kW	Efficiency	Load Factor	Operating Hours/Year	Demand kW	Energy (kW/Year)
Elevator Damp Dolomite		1	7.5	84.0%	70.0%	7,300	6.25	45,625
Fan Dry Drum Dolomite	4AMY225M642	1	37	91.1%	18.5%	7,300	7.5	54,750
Crane		4	22	88.5%	30.0%	2,190	7.4	65,329
		4	22	88.5%	30.0%	2,190	7.4	65,329
		4	7.5	84.0%	30.0%	2,190	2.6	23,464
Motor: Air Screw Pump		1	90	91.0%	70.0%	1,460	69.2	101,077
Motor: Air Screw Pump		1	75	91.0%	80.0%	1,460	65.9	96,264
Process Line: Soda								
Elevator	4A	1	5.5	84.0%	50.0%	1,000	3.2	3,274
Crush	4A	1	15	87.5%	70.0%	2,000	12	24,000
Weight Line #1								
Transporter		1	5.5	84.0%	50.0%	4,000	3.2	13,095
Mix	4AM225M642	1	37	91.0%	31.5%	8,760	12.8	112,128
Elevator		1	15	87.5%	50.0%	1,000	8.5	8,571
Transporter		1	11.5	85.5%	50.0%	4,000	6.7	26,901
Weight Line #2								
Mix	4A	2	37	90.2%	30.0%	7,665	12.3	188,651
Elevator		1	15	87.5%	50.0%	1,000	8.5	8,571
Transporter		1	7.5	84.0%	50.0%	2,000	4.4	8,929
Transporter		1	5.5	84.0%	50.0%	2,000	3.2	6,548
Fan	4A	1	30	88.5%	70.0%	7,665	23.7	181,881
Fan	4A	1	30	88.5%	70.0%	7,665	23.7	181,881

End-Use Category	Type	Qty.	Capacity kW	Efficiency	Load Factor	Operating Hours/Year	Demand kW	Energy (kW/Year)
Fan		1	11	85.5%	70.0%	2,400	9.0	21,614
Mill for Coil (Crush)	AO	1	17	87.5%	70.0%	2,304	13.6	31,334
Lighting			65	91.0%	50.8%	4,000	33	132,000
Repair Tools			35	90.0%	20.0%	1,000	7	7,000
Shop #1, Part #1								
Fan for Cooling Line #1	4A	1	160	93.5%	70.0%	2200	119.7	263,529
Fan for Cooling Line #2		1	132	95.5%	77.8%	2200	107.6	236,720
Fan for Cooling Line #3	4A180M	1	18.5	88.0%	70.0%	4,400	14.7	64,750
Furnace for Burning	currently under construction							
Fan for Cooling, Furnace #1	4A260M	1	37	91.0%	70.0%	4,400	28.4	125,231
Fan for Cooling, Furnace #2	4A260M	1	37	91.0%	70.0%	4,400	28.4	125,231
Raw Material Supply		2	6	84.0%	84.0%	4,000	6	48,000
Repair Tools			30	88.5%	20.0%	2,000	6	12,000
Lighting			39		100.0%	8,000	31	248,000
Shop #1, Part #2								
Fan for Cooling Line		1	95	92.8%	58.2%	4,400	59.6	26,2240
Fan for Cooling Line	4A280	1	130	93.0%	60.0%	4,400	83.8	369,032
Fan for Glass Furnace #1	4AM-200M6Y3	1	22	90.0%	43.8%	3000	10.7	32,100
Fan for Glass Furnace #2		1	22	88.5%	60.0%	3000	14.9	44,746
Fan for Glass Furnace #3	4AM-200M	1	22	90.0%	60.0%	3,000	14.6	44,000
Fan for Combustion Furnace	4AMUP200Y3	2	22	90.5%	0.0%	0	0	0
Fan		1	7	84.0%	50.0%	8,000	4.1	33,333

End-Use Category	Type	Qty.	Capacity kW	Efficiency	Load Factor	Operating Hours/Year	Demand kW	Energy (kW/Year)
Supply Raw Materials		2	6	84.0%	66.7%	1,000	4	8,000
Lighting			32		96.9%	8,000	31	248,000
Shop #2								
Fan for Processing Line #5		1	90	91.0%	39.9%	8,760	39.5	346,020
Fan for Processing Line #6	SEN 2601	1	90	91.0%	46.1%	8,760	45.6	399,456
Fan for Processing Line #7		1	90	91.0%	48.9%	8,760	48.4	423,984
Fan for Processing Line #8	MBM 2805 (ASEA)	1	75	91.0%	39.9%	8,760	32.9	288,204
Fan for Processing Line #9		1	90	91.0%	41.9%	8,760	41.4	362,664
Fan for Processing Line (India)		1	132	92.0%		2,920		0
Furnaces for Burning, #5-8		4				8,760		0
Furnace for Burning #9		1		93.0%		8,760	105.5	924,180
Fan for Cooling Furnace #6		1	37	90.2%	20.2%	7,300	8.3	60,590
Fan for Cooling Furnace #7		1	37	90.2%	40.0%	7,300	16.4	119,778
Fan for Cooling Furnace #8		1	22	88.5%	30.6%	7,300	7.6	55,480
Fan for Cooling Furnace #9		1	37	90.2%	37.3%	7,300	15.3	111,690
Fan for Cooling Furnace #10	4AM225MBY2	1	30	90.0%	40.0%	7,300	13.3	97,333
Fan for Cooling Furnace #11		1	37	90.2%	27.8%		11.4	0
Vacuum Pump		1	37	90.2%		5,840	reserve	
Vacuum Pump		1	75	91.0%		5,840	reserve	
Vacuum Pump	4AM280M3931P23	1	75	91.0%	51.0%	5,840	42	245,280
Fan for Combustion #1		1	30	88.5%		0		0
Fan for Combustion #2		1	37	90.2%		0		0

End-Use Category	Type	Qty.	Capacity kW	Efficiency	Load Factor	Operating Hours/Year	Demand kW	Energy (kW/Year)
Fan for Combustion Filter		1	45	90.2%		0		0
Supply Raw Materials		2	15.5	87.5%	90.3%	4,000	16	128,000
Line Breakage Glass		1	48	90.2%	67.7%	8,000	36	288,000
Lift		1	20	88.0%	44.0%	2,190	10	21,900
Repair Tools			31		19.4%	2,190	6	13,140
Lighting			80		50.0%	8,760	40	350,400
Boiler Stations								
Hot Water Pump #1	4AM225-M4Y3	1	55	92.5%		4,400	reserve	
Hot Water Pump #3	A2	1	17	87.0%		4,400	reserve	
Hot Water Pump #4	4AMH225-M4Y3	1	75	92.5%	78.2%	4,400	63.4	278,960
Hot Water Pump #5	MO250-5-4Y3	1	75	91.0%	78.0%	4,400	reserve	0
Hot Water Pump #6	A2	1	30	88.5%	78.0%	4,272	26.4	112,955
Feed Pump #1	AUR180M2Y3	1	30	88.5%	92.0%	4,400	31.2	137,280
Feed Pump #2	AUR180M2Y3	1	30	88.5%	92.0%	4,400	reserve	0
Feed Pump #3	4AMH225-M2Y2	1	45	90.2%	61.3%	4,400	30.5	134,634
Fan Exhaust #1	AO2-91-6	1	17	87.0%	25.6%	4,400	5	22,000
Fan Exhaust #2	AO2-91-6	1	17	87.0%	20.5%	4,400	4	17,600
Fan Supply #1	AO2-62-8/6/4	1	13	86.5%	33.3%	4,400	5	22,000
Fan Supply #2	AO2-62-8/6/4	1	13	86.5%	20.6%	4,400	3.1	13,640
Pump #1	AUR100L2Y2	1	5.5	88.0%	78.0%	730	4.875	3,559
Pump #2	A4	1	7.5	84.0%	78.0%	730	6.9	5,084
Lighting			5		50.0%	8,760	2.5	21,900

End-Use Category	Type	Qty.	Capacity kW	Efficiency	Load Factor	Operating Hours/Year	Demand kW	Energy (kW/Year)
Waste Water Pump Station								
Waste Water Pump #1		1	45	90.2%	20.0%	876	10.0	8,760
Waste Water Pump #2		1	40	90.2%	22.6%	876	10.0	8,760
Waste Water Pump #3		1	55	91.0%	16.5%	876	10.0	8,760
Drain Pump		1	5	84.0%	67.2%	1,000	4	4,000
Lighting			3		50.0%	4,000	1.5	6,000
Water Supply								
Water Pump		5	17	87.0%	300.0%	0	51	0
Lighting Outside			40	75.0%	56.3%	4,000	30	120,000
Mechanical Shop								
Tools			325		20.0%	2,000	65.0	130,000
Lighting			21		47.6%	4,000	10	40,000
Film Shop								
			100		38.0%	2,000	38.0	76,000
Lighting			2		75.0%	4,000	1.5	6,000
Liquid Shop								
			50		50.0%	2,000	25.0	50,000
Lighting			9		50.0%	4,000	4.5	18,000

Table A.2: Summary of Electricity Consumption:
Comparison of Measured End-Use Consumption to Electricity Bill

	Electricity Consumption (kWh/yr)
Subtotal of Consumption from List of Equipment (Table A.1)	23,790,068
Small Motors (Assumed to be 10% of Total from Billing Data)	3,224,500
Total Above	27,014,568
Total from Billing Data	32,245,000
Electricity Consumption Not Accounted for	5,230,432
Percentage Error	16.2%

Appendix 2: Summary Calculations for Heat Recovery System

Assumptions:

- Methane fuel rather than natural gas for mass balance
- Methane-based gas has higher heating value (energy content) of 9,600 kg-cal/m^3
- 2% excess oxygen by volume in (dry) exhaust gas (tested)
- Natural gas fuel density = 0.796 kg/m^3
- Furnace fuel consumption:
  - Furnace 3 = 12,139,000 m^3/yr
  - Furnace 2 = 3,803,000 m^3/yr
  - Furnace 1 = 4,438,000 m^3/yr
- Furnace operation:
  - Furnace 3 = 8,760 h/yr
  - Furnace 2 = 8,760 h/yr
  - Furnace 1 = 8,760 h/yr
  - This ignores furnace downtime for reconstruction. Furnaces are reconstructed approximately every 3 years. It is unknown how long the furnace is down during these periods.
- Furnace exhaust gas temperature
  - Exhaust gas temperature ranges from 300°C to 350°C, but has not been confirmed.
  - Minimum available 300°C
  - Minimum acceptable 150°C (to prevent acid condensation problems)
- Boiler data
  - There are two steam water-tube boilers, only one boiler typically operates. A shell and tube-type heat exchanger uses the steam to heat three hot water loops.
  - Peak boiler load = 7.5 tonne/h @ 80% efficiency and 440 kg-cal/kg-steam
  - Peak boiler load = 550 m^3/h
  - Fuel consumption = 2,784,000 m^3/yr
  - Average boiler combustion efficiency = 84% (tested)
  - Average boiler thermal efficiency = 70%
  - Operating hours = 8,760 h/yr
- Hot water data
  - Total flow rate = 350 m^3/h constant volume (metered)

Combustion Process

$$1.00\ CH_4 + 2.18\ O_2 + 8.20\ N_2 \equiv 1.00\ CO_2 + 2.00\ H_2O + 0.18\ O_2 + 8.20\ N_2$$

Mass Units

$CH_4 = 16$ $O_2 = 32$ $N_2 = 28$ $CO_2 = 44$

$H_2O = 18$

Therefore, 1.00 volume CH_4 produces 11.38 volume exhaust gas

$$1.00\ CH_4 \equiv (1.00 + 2.00 + 0.18 + 8.20 \text{ exhaust gas}) = 11.38 \text{ exhaust gas}$$

and 1.00 kg-CH_4 produces 19.71 kg-exhaust gas

1.00•(16) CH_4 ≡ [(1.00)•(44) + (2.00)•(18) + (0.18)•(32) + (8.20)•(28) exhaust]

16.00 kg-CH_4 ≡ 315.36 kg-exhaust gas

Exhaust gas mass flow rate

- Furnace 3
  Fuel Consumption = [(12,139,000 m³/yr)•(0.796 kg-fuel/m^3)]/(8,760 h/yr)
  Fuel Consumption = 1,103.0 kg-fuel/h
  Exhaust Flow = (1,103.0 kg-fuel/h)•(19.71 kg-exhaust/kg-CH_4) = 21,740 kg/h
- Furnace 2
  Fuel Consumption = [(3,803,000 m³/yr)•(0.796 kg-fuel/m^3)]/(8,760 h/yr)
  Fuel Consumption = 345.6 kg-fuel/h
  Exhaust Flow = (345.6 kg-fuel/h)•(19.71 kg-exhaust/kg-CH_4) = 6,812 kg/h
- Furnace 1
  Fuel Consumption = [(4,438,000 m³/yr)•(0.796 kg-fuel/m^3)]/(8,760 h/yr)
  Fuel Consumption = 403.3 kg-fuel/h
  Exhaust Flow = (403.3 kg-fuel/h)•(19.71 kg-exhaust/kg-CH_4) = 7,949 kg/h

Maximum heat recoverable from exhaust gas
(q=m•Cp•Δt)

- Furnace 3
  q = (21,740 kg/h)•(0.25 kg-cal/kg-°C)•(300 - 150°C)
  q = 815,250 kg-cal/h
- Furnace 2
  q = (6,812 kg/h)•(0.25 kg-cal/kg-°C)•(300 - 150°C)
  q = 255,450 kg-cal/h
- Furnace 1
  q = (7,949 kg/h)•(0.25 kg-cal/kg-°C)•(300 - 150°C)
  q = 298,088 kg-cal/h
- All furnaces
  q = 1,368,788 kg-cal/h

Thermal energy required for hot water system
(q=m•Cp•Δt)

- Mean boiler consumption (based on annual fuel consumption)
  Mean fuel consumption = (2,784,000 m³/yr)/(8,760 h/yr)
  Mean fuel consumption = (317.81 m³/h)

- Mean boiler load (based on annual fuel consumption)
  q = [(2,784,000 m³/yr)•(0.70)•(9,600 kg-cal/m³)]/(8,760 h/yr)
  q = 2,135,670 kg-cal/h

- Mean temperature rise requirement ($q=m \bullet Cp \bullet \Delta t$)
  Δt = (2,135,670 kg-cal/h)/[(350 m^3/h)•(1,000 kg/m3)](1 kg-cal/kg-°C)]
  Δt = 6°C

- Peak boiler load
  q = (7.5 tonne/h)•(2,000 kg-steam/tonne)•(0.80)•(440.0 kg-cal/kg-steam)/(9,600 kg-cal/m^3)
  q = 550 m^3/h

- Peak temperature rise requirement
  Δt = [(550 m^3/h)•(0.80)•(9,600 kg-cal/m^3)]/[(350 m^3/h)•(1,000 kg/m3)](1 kg-cal/kg-°C)]
  Δt = 12°C

Boiler fuel energy avoided by heat recovery:

- Furnace 3
  Fuel = [(815,250 kg-cal/h)•(8,760 h/yr)]/[(0.70)•(9,600 kg-cal/m^3)]
  Fuel = 1,062,737 m^3/yr
- Furnace 2
  Fuel = [(255,450 kg-cal/h)•(8,760 h/yr)]/[(0.70)•(9,600 kg-cal/m^3)]
  Fuel = 332,997 m^3/yr
- Furnace 1
  Fuel = [(298,088 kg-cal/h)•(8,760 h/yr)]/[(0.70)•(9,600 kg-cal/m^3)]
  Fuel = 388,579 m^3/yr
- Total all furnaces
  Fuel = 1,784,313 m^3/yr
- Energy reduction as a percentage of boiler consumption
  Savings = (1,784,313 m^3/yr)/(2,784,000 m^3/yr)
  Savings = 64%

Note: To install a heat-recovery unit in the exhaust system may require the installation of a fan to overcome the pressure drop and force the exhaust gases up the stack. Also, a hot water distribution system will require additional pumping energy to overcome increased pressure drop.