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INDUSTRIAL ENERGY EFFICIENCY AUDIT REPORT

GALATZ IRON AND STEEL WORKS
Galatz, Romania

JANUARY 1992

PREPARED BY: RESOURCE MANAGEMENT ASSOCIATES OF MADISON, INC.
Madison, WI

and

INSTAPART
Bucharest, Romania

U.S. EMERGENCY ENERGY PROGRAM FOR EASTERN AND CENTRAL EUROPE

U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT
BUREAU FOR EUROPE
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U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT
BUREAU FOR EUROPE
OFFICE OF DEVELOPMENT RESOURCES
ENERGY & INFRASTRUCTURE DIVISION
WASHINGTON, D.C. 20523

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List of Abbreviations

i. Eastern Europe Industrial Energy Efficiency Program

The countries of Eastern Europe face unprecedented changes both in their political and economic systems. To aid in the transition to market economies, the U.S. Agency for International Development (USAID) designed the Eastern Europe Emergency Energy Program. Resource Management Associates of Madison, Inc. (RMA) is the technical assistance contractor for the Industrial Energy Efficiency Component (IEEC) of the program in Romania.

The Industrial Energy Efficiency Component was designed to address the problems of industrial energy efficiency with a short-term program aimed at the immediate needs of industry. The program involves three main activities:

1. To identify and implement cost-effective low-cost/no-cost energy improvements, with an emphasis on oil savings.

2. To conduct energy audits and transfer energy auditing and management techniques, including financial and economic analysis.

3. To provide energy auditing and/or energy efficiency equipment to implement the program objectives, improve energy management, and identify additional energy efficiency opportunities.

The IEEC program deliverables consist of plant audit reports, a policy and institutional analysis report, an industry profile report, and the in-country audits, training, and equipment delivery and installations. The tasks are being carried out by a team of energy specialists and policy analysis experts in four different phases:

- Phase One: Screening - During this phase the plants to be audited will be identified, and a specific plan to implement the following phases developed and put in place.

- Phase Two: Industrial Plant Energy Audit/Training - A team of energy specialists will arrive in-country and perform a detailed energy audit at the eight selected industrial sites. They will identify short-term energy efficiency measures, develop recommendations to implement these measures, demonstrate and train plant personnel on auditing techniques, and demonstrate financial and economic methodologies for justifying energy improvement projects. Additional equipment will be ordered for Phase Three.

- Phase Three: Implementation - The recommendations identified in Phase Two will be implemented, evaluated, and modified as necessary. Additional training will be provided and the final energy efficiency equipment turned over to the host country.

- Phase Four: Analysis of Factors - This phase will analyze the factors that make up energy efficiency management and investment decision making. Recommendations for policy reform and options for enhanced energy management will be identified and a program for implementation suggested.

Energy monitoring and testing equipment will be turned over to the Romania industrial sector and the Government of Romania (GOR). The GOR will be provided with analysis and recommendations for further energy efficiency measures.

ii. Executive Summary

The Galatz Iron and Steel Works is the third largest plant of its kind in Europe. It's large size and integrated capability is now a disadvantage because fuel and material shortages prevent the plant from operating in a profitable mode. It is, however, critical for Romania to restore the plant's profitability because of the potential for world trade.

Energy consumption is critical because iron and steel production is very energy intensive. In addition, much of the energy used is imported from the U.S.S.R. and must be paid for in convertible currency.

While the auditing effort was limited in comparison to the needs of the facility, it did reveal a major deficiency that permeates the whole organization. For the past fifteen years, Romania has not been allowed to import technology that would allow measurement and control of energy use. Thus, monitoring of energy use and initiation of an energy efficiency program must become a high priority.

The technical staff at Galatz are quite competent, and with even the relatively small amount of assistance provided by this program, will be able to achieve tremendous savings. The audit team's recommendation for the plant - that of reducing combustion air in the blast furnace - has a projected savings of over a half million dollars (17,660,00 lei at 35.32 lei/$). It is imperative that further technology be provided not only to this industry, but to others throughout the country.

The hot roll strip mill was chosen for the audit, since approximately 25% of the total plant energy is consumed in this process. Of primary interest was flue gas analysis and temperature of the furnace walls. Resulting from the audit, short-term recommendations were made for improvement in combustion efficiency, furnace insulation and cooling water flow, and reduction of excess air to the furnace. Long-term recommendations included the purchase of metering and instrumentation to measure and control energy usage.

The implementation phase was conducted at Galatz from Monday, July 29 through Friday, August 2. All equipment purchased by the project for Galatz is portable, thus the main focus of the implementation phase was on training staff in the use of the equipment. The draft audit report was reviewed with plant staff, and a plan for using the equipment was developed.

1.0 Plant Description

1.1 General Information

The integrated Iron and Steel Works of Galatz was built by Romania to help industrialize and develop the Romanian economy. The building process began in 1961. The facility is located on the Danube River and has an ore harbor. It was designed by the Romanian design Institutes, IMPROMET and IPROLAM, of Bucharest. Fifty percent of the equipment was built by Romanian companies with the remainder being built by foreigners.

Galatz is the third largest iron and steel works in Europe, with the capacity to produce ten million metric tons of steel products per year. However, due to shortages of raw materials and energy, production is down to approximately twenty-five percent of capacity. Officials reported that the financial break-even point is 15,000 metric tons per day, but they were now producing only 12,000 metric tons per day.

Most iron ore is purchased from the U.S.S.R. in convertible currency. Some is purchased from other areas of the world such as India and Africa. Natural gas, coal, and electricity are all used, much of which is also purchased outside of the country with convertible currency. Furnace gas, which is a by-product of one of the operations, is also used in the processing. The company produces a comprehensive line of products including hot rolled flat products, cold rolled flat products, various iron products, coke and chemical products, and various gaseous products such as liquid oxygen, nitrogen, and argon.

Figure 1 illustrates a flow diagram of the integrated facility.

1.2 Process Description

The facility is composed of integrated plants. It has coking plants; furnaces for ingots, blooms and rolled billets; oxygen and other gaseous plants; and hot and cold rolling mills. Because of the size and complexity of the facility, the audit team concentrated on one area of the process, the hot strip mill. This is one of the largest fuel consuming areas, and was reported by the staff to consume 25% of the total purchased natural gas.

In the hot strip mill, semi-finished slabs of metal, measuring 9000mm x1500mm x 200mm, are introduced into one of five furnaces where they are heated to 1250 - 1300 °C. The slabs are then passed through the rolling frames where the thickness is reduced to an average of 6-8 mm. The final part of the operation is to pass the sheets through a coiling device that puts them into a roll.

The furnaces are heated with a mixture that consists of natural gas and furnace gas, produced in the plant's own operation. Natural gas has a heating value of 8050 kcal/m^3 and the furnace gas has a heating value of 805 kcal/m^3.

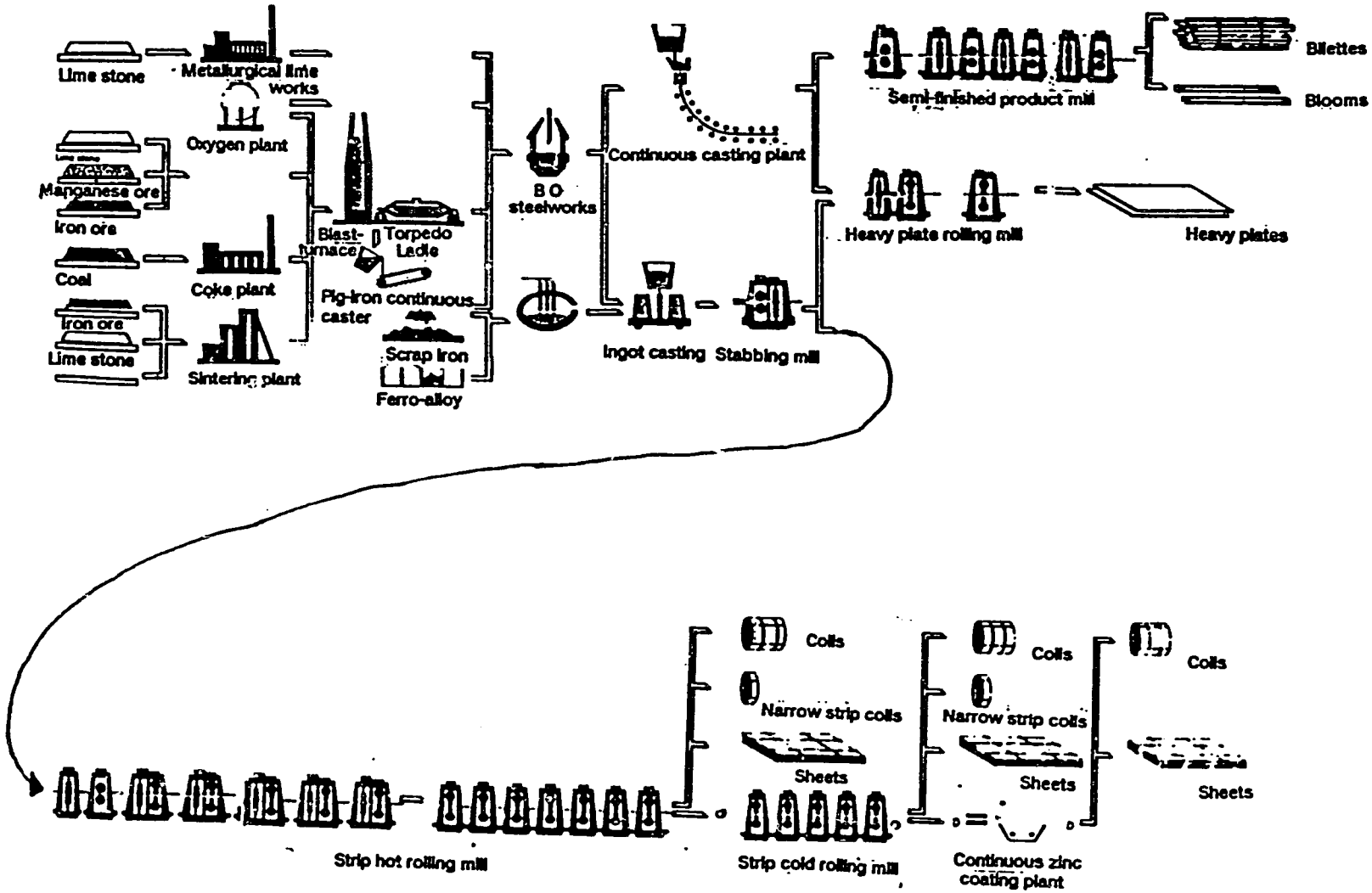


Figure 1. Process Flow

1.3 History of Energy Efficiency Measures

The hot strip rolling mill was put into service in 1971, with the furnaces for heating the metal being built in stages and completed in 1975. Efforts began in 1980 to reduce fuel consumption, at which time only natural gas was being used for fuel.

The first step to conserve energy was to partially substitute natural gas with furnace gas that resulted from the iron making process. A 15% reduction in natural gas consumption was obtained from using the mixture of natural gas and furnace gas. This is an important savings, since natural gas is in short supply, and much is imported with convertible currency.

The next step was to recover the heat from the combustion gasses from the furnaces by installing combustion air preheaters and waste heat boilers. This increased combustion efficiency and reduced the use of energy used to produce steam.

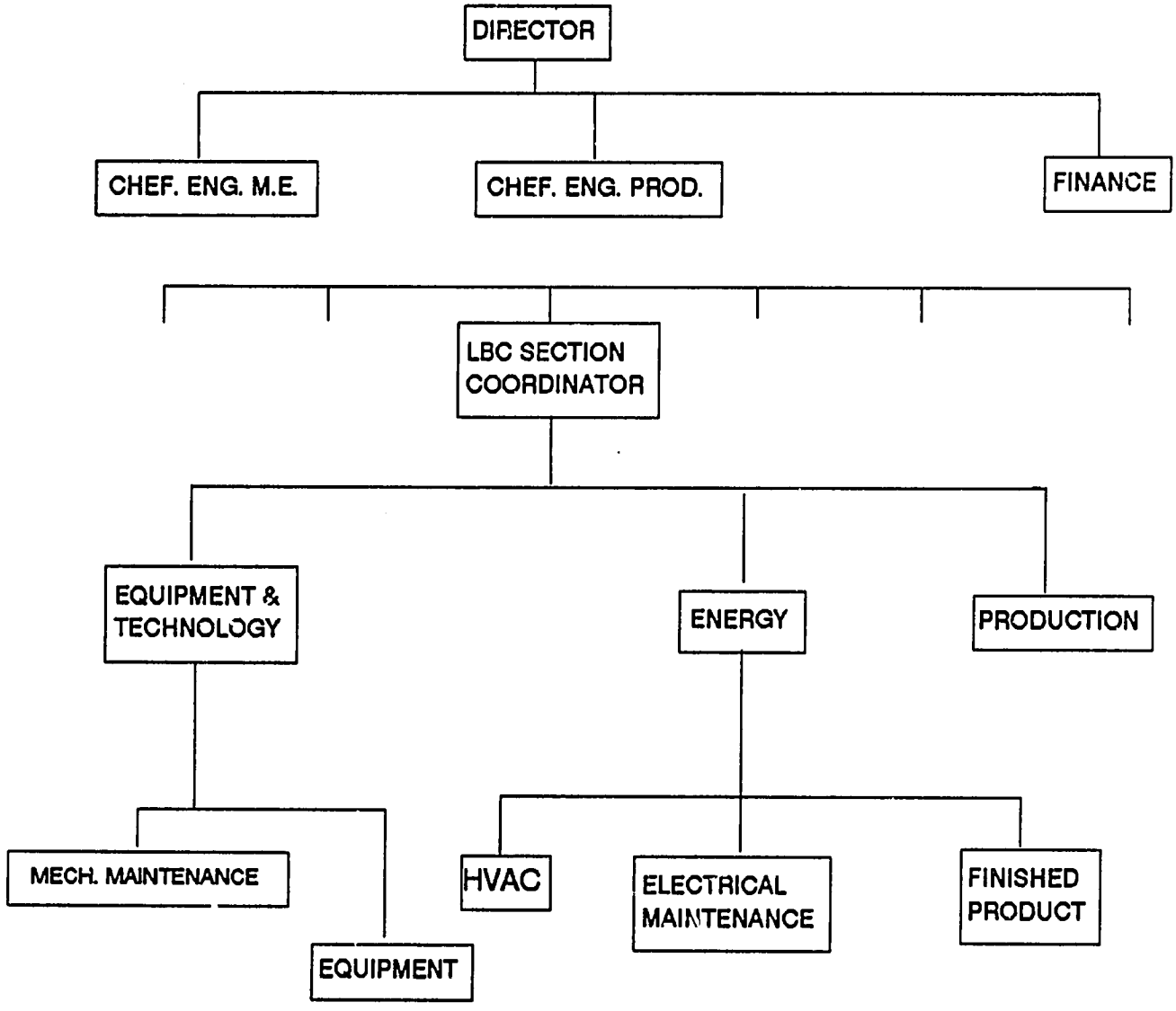
Plant personnel are studying ways to improve the control and pressure of the furnace gas that is now fed to the furnaces via ducts, with registers to control and direct flow. Pressure variations cause subsequent variations in the energy going to the furnace. Air penetration into the ducts is also a problem. They are also trying to develop a method of loading the furnaces with the slabs in the warm state. Plant personnel estimate that if slabs could be loaded at a temperature of 600 °C, 10-15% of the total energy in the slab could be saved.

1.4 Plant Management Organization

The overall organizational structure for the facility of 50,000 employees is large and complex, however, there is a similarity within the section organizations. A typical organizational chart for a section is given in *Figure 2*. Personnel are very conscious of energy usage, and each section has one individual charged with that responsibility. The facility is, however, a long way from having an efficient energy management program. There are two reasons for this. The first, and most important, is that there is almost a complete lack of metering and testing equipment. Most estimates of natural gas usage for example, are made by calculating the amount of flow through a given size opening with an estimated pressure.

The second reason is that methods of economic justification for projects have typically been based more on production needs than on economic evaluation of specific projects. Energy management training in the techniques for organizing and managing an energy program should be a vital part of the new privatization effort, with its corresponding new management requirements.

Figure 2. Organizational Chart



2.0 Plant Energy Profile

2.1 Energy Consumption Data

Table 1 shows 1989 consumption of both electrical energy and natural gas, and production in the strip mill operation. There is some correlation between production and energy usage that could be helpful to a further evaluation of energy conservation efforts. The accuracy of measurement is somewhat questionable considering the lack of instrumentation, and could account for some of the variation in energy usage per metric ton of product. *Figure 3* is a graph of energy intensity for electricity and natural gas. There is not a significant variation in energy intensity by production, but a slight trend toward decreasing energy intensity for increased production levels is noticed.

The furnaces of the strip mill operation reportedly use 104.1 m^3 of natural gas per metric ton of product. This number can be used as a benchmark for further evaluation of energy reduction efforts.

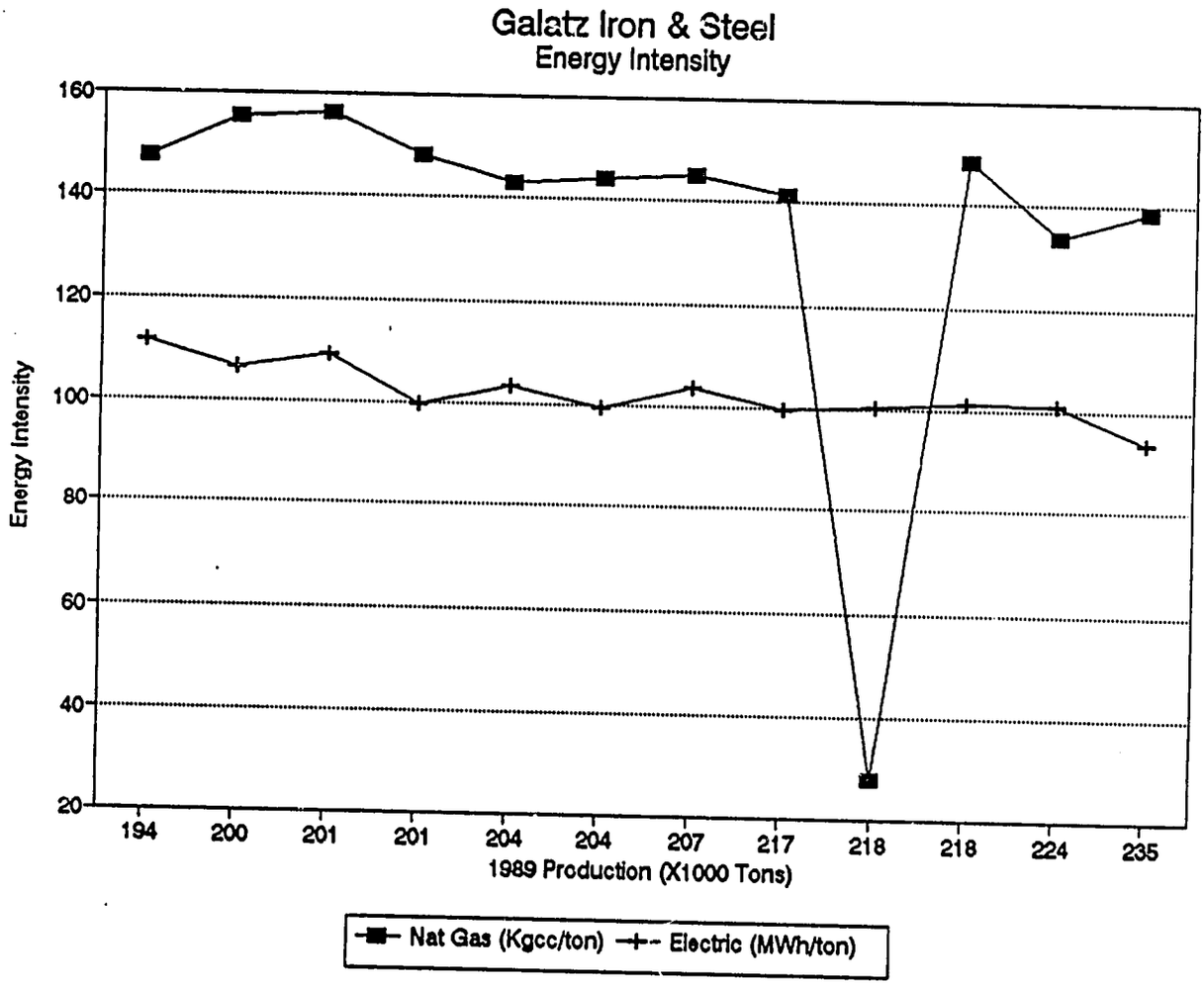
Table 1. 1989 Energy Consumption

	Production (1000 metric tons)	Electricity/ Unit Product (MWh/1000 metric tons)	Electricity Consumption (MWh)	Gas Consumption /Unit Product (Kgcc/ metric ton)	Gas Consumption (Kgcc)
Jan	203.60	103.50	21079	143.00	29.11
Feb	203.68	99.42	20225	143.93	29.32
Mar	206.72	103.63	21424	145.03	29.98
Apr	201.49	99.75	20099	147.90	29.80
May	201.44	109.10	21977	156.08	31.44
Jun	234.90	93.70	22067	138.76	32.59
Jul	217.80	101.32	21367	148.13	32.26
Aug	200.26	106.70	21367	155.38	31.12
Sep	216.56	99.71	21593	141.23	30.58
Oct	217.77	100.42	21869	139.05	30.28
Nov	224.41	100.91	22645	133.79	30.02
Dec	193.99	111.70	21670	147.29	28.57

1 Kgcc = 7000 kcal

Energy Costs: 1kWh = 1.2 lei
1m^3 NG = 2.8 lei

Figure 3. Energy Intensity



3.0 Audit Description

3.1 General

The audit had a twofold purpose: to identify both short and long range opportunities to reduce energy; and, to train personnel in both the techniques of auditing and the use of modern instruments. The audit team also encouraged plant staff to assist in the economic evaluation of identified projects.

3.2 Audited Area

The hot strip rolling mill was chosen because approximately 25% of the total plant energy is consumed there, and because there appeared to be opportunities to demonstrate quick payback.

3.3 Audit Methodology

The audit was initiated with a tour of the operation on the first afternoon to determine the kind of instrumentation needed, and any adaptations required to instruments. For example, extension tubes had to be made for the combustion gas analyzer in order to reach through the thick furnace walls.

3.4 Data Gathering Process

Of prime interest was flue gas analysis and the temperatures of the furnace walls. The combustion analyzer was used for the flue gas analysis, with some interpretation of results. Because of the mixture of natural gas and furnace gas, the audit team did not have known calorimetric information to feed into the analyzer, which was taken into consideration in the readings. Furnace wall temperatures were measured with the Heat Spy infrared gun. Flow measurements of cooling water to the furnaces were attempted with the ultrasonic flow meter, but because of a malfunction of the instrument, readings were not obtained.

Flue gas samples were obtained at various locations in the system, some before heat exchangers, and some after. The audit team was able to take samples with a balloon in locations where it was too difficult to set up and use the analyzer.

4.0 Summary of Results

4.1 Furnace Combustion Efficiency Improvement

Based on the latest complete production and energy usage data from 1989, the hot strip rolling mill produced 2,584,180 metric tons of steel and used 104.1 m^3 natural gas/metric ton.

The original combustion analysis indicated an excess air of 168%, with a corresponding combustion efficiency of roughly 60%.

A very conservative estimate of 2.5% improvement in combustion efficiency gives the following savings:

104.1 m^3 NG/metric ton x 2.5% = 2.6 m^3 NG/metric ton
2.6 m^3 NG/metric ton x 2,584,180 metric tons = 6,718,868 m^3 NG
6,718,868 m^3 NG x 2.8 lei/m^3 NG = 18,812,830 lei savings/yr

At the present exchange rate of 35 lei/$ this equals $537,509.

Additional savings would result from both the reduced loss in metal due to scale and the reduced fan energy use. The plant technical staff did additional calculations and came up with a total yearly savings of 3,668,505 lei for scale reduction and 28,800 lei for fan energy reduction. This would yield a total savings of $643,147.

4.2 Furnace Wall Insulation

With the use of the infrared gun, furnace wall temperatures were measured at 450 °C, or 842 °F.

Based upon the experience of plant staff, it was estimated that restoring or improving the wall insulation would decrease yearly natural gas consumption by 0.5%. This would result in the following savings:

269,013,138 m^3 NG/yr x 0.5% = 1,345,066 m^3 NG savings/yr
1,345,066 m^3 NG x 2.8 lei/m^3 = 3,766,183 lei/yr savings

This is equivalent to $107,605, at 35 lei/$.

4.3 Furnace Cooling Water Flow

Due to a malfunction of the flow measurement device, the audit team was unable to make the desired measurements of cooling water flow to the furnaces. Plant personnel believed that the flow was excessive, but because of lack of measuring equipment, were reluctant to reduce it closer to a critical point.

Staff estimated a 10% reduction in flow would lead to an electric power reduction of 261,000 kWh/yr.

261,000kWh x 1.2 lei/kWh = 313,200 lei/yr.

This is equivalent to $8,948, at 35 lei/$.

4.4 Electrical Improvement

If the combustion efficiency is to be increased by 2.5%, through the use of portable combustion analysis equipment, there will be a resulting decrease in the combustion air required. It is necessary to supply air to maintain a 10:1 ratio of air to natural gas, and 20% to 30% excess air is acceptable. However, one furnace in the hot rolling mill was measured at 168% excess air.

Excess air can be reduced through the use of dampers, but this is a relatively inaccurate approach. A better way to proceed is to install variable speed drives on the large blower motors providing combustion air. An AC power analyzer could be used to monitor electrical energy used by these motors, so that an economic justification can be prepared for the variable speed drive.

The overall average plant electrical load is 29 MW, much of which is concentrated in very large motors of as much as 900 kW. Thus, in addition to analysis of the combustion blower motors, AC power analysis could be used throughout the plant to justify power factor correction and electrical efficiency improvements.

A sensitivity analysis shows that even a small efficiency improvement of 0.1% would result in reasonable payback for this equipment:

1989 Electrical consumption: 257,382 MWh
257,400 MWh x 0.1% = 257.4MWh/yr
257.4MWh x (1000kWh/MWh) X 2 lei/kWh = 515,000 lei/yr

At the present exchange rate of 35 lei/$ this equals $14,710/year. The cost of the equipment is estimated at $5,500. Therefore, payback with only 0.1% improvement would be 4 months.

4.5 Recommended Immediate Actions

It is recommended that the plant concentrate efforts initially on the low-cost/no-cost energy conservation opportunities (ECO's). The first priority would be to improve combustion efficiency by closer control of excess air. The second priority would be to inspect furnace insulation and air leaks.

4.6 Recommended Long-Term Actions

A major objective of long-term actions should be to have enough metering and instrumentation so that a reliable baseline of energy usage can be established. This information would be useful in several ways. First, it is a method of independent verification of energy purchased from suppliers. Second, it allows the development of an energy index for specific operations, as well as the complete operation. Third, with this index, good decisions can be made with regard to the best utilization of critical energy resources. For example, energy intensive products may have to be either eliminated or curtail 1 as energy availability becomes critical.

The next effort should be to develop a priority list of energy projects. This priority would be based on the many factors that influence such decisions, economics being just one. Some of the potential long range projects already identified - but not prioritized - are automatic controls for combustion, a method for reducing the pre-heating of slabs, and a better way to control both the caloric and pressure variations in the gas mixture fed to the furnaces. This would reflect not only in the energy savings, but the quality of product as well.

4.7 Follow-up Actions

Follow-up to this project should include purchase of the recommended equipment and adequate training to insure the maximum utilization of the equipment. Plant personnel are quite competent technically and with a minimum of effort and equipment, should be able to make vast improvements in the efficiency of the operation.

4.8 Replication Potential

The replication potential extends to every combustion process involved in the production of ten million metric tons of steel per year. The potential savings are significant.

5.0 Plant Management Organization

5.1 Findings

The organization appears to be operating on the same organizational structure as before the revolution. This is much different from some plants which produced a new corporate like organizational structure. Plant personnel are, however, very conscious of energy costs and availability, and do have staff appointed with responsibility for energy.

5.2 Recommended Actions to Promote Energy Efficiency

The first step is to provide instrumentation and metering equipment. The lack of this equipment is the major reason why so many items with high payback were identified. Put simply, if they can't measure it, they can't manage it. The equipment listed below was discussed in detail with plant staff, and represents a minimum required to obtain necessary energy data for management and control.

As foreign technology for improving energy efficiency becomes more available, an energy management structure should be developed to receive and digest the information. This structure should include well defined responsibility for energy management, a baseline and energy index, a priority list of projects, and an education component that will offer minimum resistance to change.

5.3 Recommended Equipment List

1. Calorimeter (1) - On-line unit for analyzing combination of feed blast furnace gas and natural gas, blended.

2. Combustion Analyzer (1) - Similar to one used by the audit team, except with: a longer probe for large hot strip furnaces, and the ability to modify the fuel parameters for blended blast/natural gas.

3. Combustion Analyzer (3) - Compact unit for O_2 and CO_2 only; hand held if possible; internal buffer for collection of data and downloading to a PC Computer, with software; longer probe; and ability to modify fuel parameters.

4. Heat Spy (2) - Identical to unit used by audit team.

5. Power Factor Meter (1) - Identical to unit used by audit team.

6. Ultrasonic Flowmeter - Simpler unit than used by audit team but including a buffer for downloading to a PC Computer.

7. PC Computer/Software/Printer - (1 set) Desktop unit/color monitor for running WP, QPRO, FASER, etc.

8. Digital Thermometer (1) - Similar to unit used by audit team.

9. Air Velocity Meter (1) - For large furnace exhaust gas measurement.

10. Draft Manometer (1) - For large furnace exhaust flue gas, up to 2000mm water column.

11. AC Power Analyzer - Similar to unit used by audit team but including a buffer for downloading of data to a PC Computer. Recommend looking at a Dranetz unit.

6.0 Implementation Phase

6.1 Summary

The implementation phase at Galatz Iron and Steel Company started on Monday July 29th, and was completed on Friday August 2nd, 1991. The facility contact was Mr. Stan Ostache. All equipment purchased by the project for this facility was portable. The fundamental operation of all equipment was explained to a group of over 10 engineers and managers of engineering departments. The use of a PC computer, power analyzer and infrared heat gun were demonstrated, and several individuals were trained in the proper use of the equipment. In addition, electrical equipment operating hot roll slabs, and furnaces using coke ovens and blast furnace gas fuel, and high intensity electrical and thermal energy using areas were revisited to obtain operating information.

1. Hot Roll Slab Operating Equipment

   It is estimated that about 25 MW of electrical power is connected for hot roll slab operation. This area is equipped with a motor-generator set, AC-DC rectifiers, and various types of switching mechanisms for control. A 100 kW motor, operating a section of the roller conveyor, was selected to demonstrate the electric power analyzer. This motor was found to be very lightly loaded, with the measured power factor at 0.14 to 0.15. The equipment in this area appears to be very old and the potential for energy and operating cost savings are relatively high. Because of the high savings potential, high capital investment is justifiable and needs to be investigated.

2. Furnaces Using Coke and Blast Furnace Gas Fuel

   All of the coke oven and blast furnace gases are mixed with natural gas and are used in the pit and hot roll strip furnaces. The furnace control is the traditional air-fuel ratio linkage. Since coke oven and blast furnace gas properties and flow rates are changing, modifications in the control strategy are needed to account for the fuel properties change. A gas chromatograph with built-in calorimeter is essential to implement the non-traditional control strategy.

Two areas appear to be highly energy intensive and the potential for energy savings is substantial. These areas are:

- Electrical Equipment for Hot Rolled Slabs. The equipment and the control are very old and the energy intensity (energy used per ton of product processed) is very high. Lightly loaded motors for conveyors operate at a very low power factor. Test data indicates power factors ranging from 0.14 to 0.15. The control mechanism and the switching apparatus are mechanical, exhibiting sparks during the operation, contributing to significant energy losses. AC to DC rectifiers and motor-generator sets are old and a source of

substantial energy loss. Any retrofit requires significant capital. However, the payback is very attractive due to the high energy intensity.

- Coke Oven and Blast Furnace Gas Fuel. These gases are produced during steel fabrication and are mixed with natural gas for metal forming and melting. Since manufactured fuel gases vary in flows and properties, a gas chromatograph with built-in calorimeter is essential for optimum furnace efficiency and combustion. This area also requires evaluation and retrofit with proper control for optimum efficiency.

6.2 In-Country Draft Audit Report Review

The draft audit report was reviewed with Mr. Stan Ostache of the Galatz Iron and Steel Complex. Mr. Cornel Rotaru of the Resource Ministry was also present during the report review. The audit, which was focused only on the hot roll strip mill, pointed out several important energy efficiency issues. The facility management has begun addressing those recommendations which will result in a considerable energy savings. However, Galatz Iron and Steel complex is a very large steel mill and power generating complex, with the capability of generating 600 MW of power. The internal power demand, at full production, is about 250 MW. The facility management and the ministry indicated a great deal of appreciation for the work accomplished thus far. They requested more technical assistance for sections of the factory which were not audited due to time constraints. A walk-through was also made to review the operation of electrical equipment transporting the hot steel slabs, the large furnaces, their control strategy, and blast furnace and natural gas mixing chambers. The equipment and controls in these areas are outdated. Some operation and control strategies need to be revised in order to reduce energy intensity and waste, as indicated in the summary.

6.3 Energy Efficiency Measures Adopted by the Facility

During the walk-through, management showed the audit team a number of pit furnaces out of commission for repair and re-insulation. They reported that many other furnaces are also scheduled for repairs. These repairs include reducing gaps to minimize infiltration, replacing damaged insulation, and inspecting dampers and ducts for plug-ups and proper operations. These energy conservation efforts have been initiated primarily due to the findings in the report and the importance of conservation in reducing operating costs.

6.4 Management Results

Some organizational changes appear to be taking place at the corporate level, including reassigning of a corporate level energy manager. However, this change could not be documented because the plant is in the early stages of organizational restructuring.

6.5 Implementation Plan

6.5.1 Equipment

It was found during training, equipment demonstration, and the description of the equipment functions, that the most frequently used equipment will likely be the power analyzer in conjunction with the PC, followed by the combustion analyzers (portable and hand-held). The velometer, ultrasonic flow meter and the other smaller monitoring equipment will be less frequently used.

To demonstrate the installation procedure, the power analyzer was installed to a randomly selected electric motor. Data was recorded for about two hours. The power analyzer was then set to stand-by and moved into an office for transferring data from the power analyzer to the PC. The power and power factor data were plotted using the Quattro spreadsheet. Hard copies of these graphs were produced using the printer, and data on the graphs was explained.

The motor was operating a conveyor which was found to be lightly loaded. The 100 kW motor was drawing about 9 kW. The measured power factor (PF) during this short duration test was about 0.14. When we explained that electrical equipment should not be operated under a PF of 0.80, management decided to test all major equipment in the roller conveyor area (estimated at over 10 MW) and will forward the results to the design institute in Bucharest for possible design modifications and power factor improvements. A similar plan is underway to use the combustion analysis information to improve the furnace efficiency internally or externally.

6.5.2 Management

A team of three engineers has been assigned to oversee the existing monitoring equipment and to provide operational support. This team will plan the operation of the existing equipment and investigate the possibility of increasing the staff and purchasing other monitoring and energy efficiency equipment for electrical and thermal systems.

6.6 Expected Energy Savings

The total power demand for roller conveyors is over 10 MW. The motor tested indicated a power factor value of 0.15. If the power analyzer and the PC are used for all of the roller conveyor motors, and corrective action is taken to increase the power factor value to about 0.50, a power demand decrease of about 3.5 MW will result. Assuming 6,000 annual hours of operation, the electrical energy saving can be estimated to be about 21,000,000 kWh/yr.

A similar calculation can also be made for thermal energy savings. The complex has 52 pit furnaces, 20 of which are operated at one time. Each pit furnace is rated at about 10,000,000 kcal/hr. Assuming that the hand-held and portable combustion analyzers are used routinely to optimize furnace operation, results should show a 1.0% efficiency

improvement. Thus, the thermal energy savings can be estimated to be over 1,300,000 m^3/yr, based on 6,000 annual hours of operation.

Other monitoring equipment supplied will generally compliment the proper use of the power and combustion analyzers. Because of the size of the complex, more metering equipment is needed to expedite the energy efficiency evaluations for all divisions.

Appendix A
List of Abbreviations

List of Abbreviations

AC	= alternating current
amps	= amperes
atm	= atmosphere = 14.696 pounds per square inch
bar	= 100,000 pascals = 14.504 pounds per square inch
BTU	= British thermal unit
cfm	= cubic feet per minute
cm	= centimeter = 0.3937 inches
cm^2	= square centimeter = 0.155 square inches
CO	= carbon monoxide
CO_2	= carbon dioxide
DC	= direct current
°C	= degree Celsius T[°C] = 5/9*(T[°F] - 32)
°F	= degree Fahrenheit
°R	= degrees Rankine T[°R] = T[°F] + 460
eff	= efficiency
ex air	= excess air
Gcal	= gigacalorie = 1 billion calories = 3.968 million BTU
GJ	= gigajoules = 1 billion joules
gph	= U.S. gallons per hour
gpm	= U.S. gallons per minute
GWh	= gigawatt hours = 1 billion watt hours
H_2	= hydrogen
H_2O	= water
H_2SO_4	= sulfuric acid
hectare	= 10,000 square meters = 2.471 acres
hectoliter	= 100 liters = 26.42 U.S. gallons
Hg	= mercury
hr	= hour
Hz	= hertz = cycles per second
J	= joules
K	= Kalvin
kcal	= kilocalories = 1 thousand calories = 3.968 BTU
Kcs	= 29.77/$1 US
kg	= kilogram = 2.2046 pounds
Kgcc	= 7,000 kcal = 27,776 BTU
kJ	= kilojoules = 1 thousand joules = 0.947813 BTU
km	= kilometer = 0.621 miles
kN	= kilonewton = 1 thousand newtons
kPa	= kilo pascals = 1 thousand pascals = 0.14504 pounds per square inch
kV	= kilovolts = 1 thousand volts
kVA	= kilovolt-amperes
kVAr	= kilovars = 1 thousand volt-amperes (reactive)
kW	= kilowatt = 1 thousand watts
kWh	= kilowatt hour = 1 thousand watt hours
lbs	= pounds
liter	= 0.2642 U.S. gallons = 0.03531 cubic feet

m	= meter = 39.37 inches
m^2	= square meter = 10.76 square feet
m^3	= cubic meter = 35.31 cubic feet
mA	= milliampere = 0.001 amperes
metric ton	= 1 thousand kilograms = 1.1023 U.S. tons
mg	= milligrams
min	= minute
MJ	= megajoules
mm	= millimeter = 0.03937 inches
MPa	= 1 million pascals = 145.04 pounds per square inch
MVA	= megavolt-amperes
MW	= megawatt = 1 million watts
MWh	= megawatt hours = 1 million watt hours
NG	= natural gas
nm	= nanometer
Nm^3	= cubic meters at standard conditions of temperature and pressure (20°C and 1 atmosphere)
NO_X	= nitrogen oxide
O_2	= oxygen
P	= pressure
PC	= personal computer
PF	= power factor
ppm	= parts per million
psi	= pounds per square inch
psig	= pounds per square inch (gauge)
R	= thermal resistance
s	= second
SO_2	= sulfur dioxide
sq ft	= square feet
Tcal	= teracalorie = 1 trillion calories = 3.968 billion BTU
T	= temperature
V	= volts
VArs	= volt-amps (reactive)
VSD	= variable speed drive
W	= watts
yr	= year