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INDUSTRIAL ENERGY EFFICIENCY AUDIT REPORT

COMBINATUL CHIMIC CRAIOVA PLANT
Craiova, 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
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U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT
BUREAU FOR EUROPE
OFFICE OF DEVELOPMENT RESOURCES
ENERGY & INFRASTRUCTURE DIVISION
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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 Combinatul Chimic Craiova Plant (CCC) is a major producer of fertilizer in Romania, and is the sole producer of chemical feedstocks for other industries. This means that feedstocks have priority over products, many of which can be exported to obtain critical hard currency.

Energy prices increased significantly in 1990 due to the removal of government subsidies, the increased cost of natural gas imported from the U.S.S.R., and the requirement to pay in convertible currency for natural gas imports. The former barter arrangements with importers were largely canceled. This has created a shortage of energy supplies throughout Romania, and a corresponding decrease in plant production levels. Energy efficiency has become a prime area of interest because of its potential for cost reduction which will maintain the viability of the plant operations.

The management of CCC is still arranged as a straight line organizational structure, similar to many other Romanian manufacturing plants. Decision making authority tends to be concentrated at the top levels, and there is an apparent lack of priority given to energy efficiency measures. The centralized structure makes communication difficult with the personnel directly cognizant of energy inefficiencies and potential remedies.

The energy audit was performed over a one-week period at the plant. Due to the large size of the manufacturing operations, the audit concentrated on the following areas: steam boilers, condensate return systems, electric air compressors, and process gas compressors. The audit revealed these key findings:

- Boilers are operating below their optimum efficiency levels due to the lack of combustion parameter information and apparent equipment oversizing. New monitoring data will enable plant staff to increase efficiency and save over 35 million lei/year in fuel costs.

- Improved condensate recovery can save over 9 million lei/year in fuel costs and recover almost 18,000 Gcal/year in thermal energy.

- The compressors are operating on extremely high recycle rates and with improperly designed pipeworks. Modifications have the potential to save over 29 million lei/year in electric costs, equivalent to almost 20 million kWh/year.

These findings cover only the oxygen plant and the acetylene plant. Further savings of this magnitude exist throughout the other plant process facilities.

The primary recommendations of the audit include:

1. Begin immediately to identify and implement low-cost energy conservation projects utilizing the instrumentation to be provided by this program.

2. Initiate changes in organizational restructuring and move rapidly toward a more flexible management organization.

3. Establish an energy management program as a part of the new structure, to move quickly toward making the plant energy efficient.

As a supplementary professional recommendation, it is proposed that a working relationship is established between Romanian energy societies and the Association of Energy Engineers, and between the University of Craiova and an U.S. educational institution.

The implementation phase of the audit involved a return trip to the facility from August 12 to 16, 1991 to expedite the installation and use of the equipment. Training on portable equipment was provided for the plant staff. Fixed energy efficiency equipment had not yet arrived at the time of the implementation visit, but extensive discussion took place on the proposed locations, installation procedures, and operation of the fixed meters. The local subcontractor, INSTAPART, will assist in the installation of the fixed equipment. The draft audit report was reviewed with the plant staff, and a utilization plan was developed for the equipment.

1.0 Plant Description

1.1 General Information

The Combinatul Chimic Craiova Plant, now called Doljchi m S.A., is one of the largest chemical works in the country, occupying 300 hectares. It was developed in four stages beginning in 1965. Until the revolution, it was the central headquarters for all eleven (11) fertilizer and five (5) organic plants located throughout the country. CCC is separated into four main processing areas: three for ammonia used in the production of fertilizer, and one for various organic products used as feedstocks for other chemical and pharmaceutical plants. This is the only plant in the country that provides chemical feedstocks to other Romanian industries. By government order, feedstock production has priority over fertilizer production, which is the plant's major export product. This priority prevents management from operating the company to its maximum efficiency. Of the three ammonia plants, one is Soviet built with a capacity of 600 metric tons/day, one is ICI built with 907 metric tons/day capacity, and one is M.W. Kellog licensed (early 70's) with a capacity of 907 metric tons/day.

1.2 Electrical

The plant is located in close proximity to a 1,000 MW coal powered thermal plant operated by RENEL, the Romanian National Electricity Utility. Electrical energy and steam are purchased from the block power facility.

Plant Loads:	Peak	190 MW
	Normal	185 MW
	Current	72 MW (50% production)
Cost:	1.7 lei/kWh (Somewhat less than normal RENEL cost because of proximity to power plant)	
Power Factor:	Total Plant: 0.89 - 0.925	
	Organic Production Plant: 0.75	
	Fertilizer Plant: 0.71 - 0.77	
	Oxygen Plant: 0.98	
Distribution:	Eight (8) 110 kV substations	

Metering is either old, non-functioning, or non-existent.

1.3 Thermal

Thermal loads are primarily in the plant steam header (plant boilers plus imported steam), and in direct-fired process heaters, reactors, and platformers. There is a small steam turbine generating 6 MW of electricity for the plant Boilers:

Quantity:	Four (4)
Manufacturer:	Romanian
Capacity:	50 metric tons/hr
Pressure:	40 bar
Temperature:	450 °C (superheat)
Fuel:	Natural gas, residue gas, fuel oil
Operation:	Two (2) gas (methane and residue) Two (2) oil fired
Firing:	Fuel oil or blended gas residue/methane. No combination burners. Mechanical atomizers (oil)
Air Preheater:	Each boiler equipped
Controls:	Manual
Metering:	Fuel consumption, fuel feed pressure, steam pressure/temperature
Cost:	430 lei/Gcal
Efficiency:	Stated to be 0.89 to 0.91 for methane fired boilers 0.88 to 0.86 for oil fired boilers

Steam Importation:

Source:	Nearby block power facility
Pressure:	13 and 18 bar, extraction turbine saturated.
Quantity:	450 metric tons/hr
Cost:	462 lei/Gcal

Steam Distribution:

Headers:	40, 23, 15, 13, 8 bar headers 40 - Direct from boilers, superheat 23 - Let down from the 40 bar header by Pressure Control Valve, also inject Boiler Feed Water to achieve saturated conditions 15 - same as 23 bar header 13 - Imported from the Thermal plant 8 - Imported and extracted from steam turbine

Steam Turbine:

Rating:	6 MW @ 40 bar, 450 °C superheat
Type:	Single stage extraction/condensing

Condensate:

Recovery:	60% of internally produced steam. 0% of imported steam, but have waste heat recovery before disposal.

Fuel Oil:

Characteristics:	Higher Heating Value: 10,500 kcal/kg. Injected at 130 °C, Stored at 60 °C. Kinematic Viscosity @ atm = 25 E (0.000194 m^2/s) @ 130 °C = 6 E (0.000047 m^2/s)

Storage Capacity: 4000 $meters^3$ fuel oil

Production is currently limited to about 50% capacity due to a shortage of fuel supply. Raw materials are a combination of indigenous and imported materials. The majority of the plant's products are used in country and not exported. Barter arrangements with the Soviet Union are no longer in effect.

The plant's imports are financed according to the following guidelines:

1. Export earnings are used to finance imports (raw materials, supplies, spare parts, new foreign capital equipment, etc.). Profits (export earnings less importation costs) are split 50/50 with the government. The company is taxed a further 50% on its retained profits.

2. If importation costs exceed export earnings, the company must take out a government loan to cover the deficit.

Personnel from the Ministry of Resources and Industry (MRI) and Combinatul Chimic Craiova (CCC) who accompanied the auditors included:

Mr. Mihail Tomsa, Director General of CCC
Mr. Mihal Stroe, Chief Electrical Engineer, CCC
Mr. Florin Prodana, Chief Thermal Engineer, CCC
Mr. Alaexandru Marinescu, Inspector General, MRI Energetics, Craiova.

1.4 Process Description

Prior to the audit team's arrival, the staff had prepared complete information on both the electrical and thermal supply systems. However, the team was unable to obtain flow sheets of some of the energy intensive processes such as the oxygen plant. A visit to the control room did not yield such information. There seemed to be some concern about revealing the process information to the auditors. Considering that one year ago, even maintenance information on machinery was classified information, this is not surprising.

Of prime interest was the operation of the air compressors with relation to the rest of the system. At full capacity, the plant averaged 150 MW of power. The two air compressors each had a 12 MW motor, or a total of 24 MW, which represented 16% of total power. In addition, the acetylene process had two 5 MW compressors which represented another 7%. Thus, the compressors in the oxygen plant and the acetylene plant together consumed 23% of the plant load.

Since the plant was operating at 50% production, and the compressors have a very poor turn down ratio, the operation appears to be wasting energy on high recycle load.

1.5 History of Energy Efficiency Measures

CCC's interest in energy conservation measures has increased significantly in the last year due to the increased cost of thermal energy. Thermal energy costs have more than tripled due to fuel price increases. The record of purchased and generated steam costs is shown below:

<u>Purchased Steam:</u>

Average annual cost

1989 -- 125.5 lei/Gcal
1990 -- 134.8 lei/Gcal
1991 -- 511.0 lei/Gcal

<u>Generated Steam:</u>

Average annual cost

1989 -- 200 lei/Gcal
1990 -- 184 lei/Gcal
1991 -- 530 lei/Gcal

There are three reasons for this price increase. In November, 1990, the Romanian Government removed subsidies for imported energy on those enterprises that were privatizing. Second, in January, 1990, the Soviet Union increased the price of imported

natural gas to Romania, and required payment in convertible currency. Third, former barter arrangements with the Soviet Union were canceled.

These escalating fuel costs and the resulting lack of fuel supplies and other raw materials, have caused production to decline to approximately 50%. The plant was not designed with this turndown ratio, so much of the larger equipment must run at near full capacity. This results in high recycle rates and fuel consumption approaching the equivalent full production rate. The result is significantly higher fuel consumption per unit of product. Since this energy crunch is relatively new, there are few documented efforts to identify energy conservation projects as such. There was an effort in the thermal section to improve combustion efficiency of the boilers, but this was hampered by the lack of combustion analysis equipment.

In 1989, CCC received a proposal from the M.K. Kellog Company for energy reduction and increased capacity in the plant Kellog had previously built in Romania. Kellog submitted eight (8) retrofit options for energy reduction at a total cost of 9.4 million dollars.

1.6 Management Organization

The plant organizational structure is similar to other industries in Romania operating under the centralized form of government. It is a line organization with Technical Directors and their staff reporting directly to the Director General. Energy is budgeted and controlled at stations by an energy dispatcher. These dispatchers have control over electrical switches, steam systems, and natural gas. Some stations have monitors for use in controlling the systems. Personnel are on duty at these stations for all three shifts.

It is the responsibility of the Technical Directors of the thermal and electrical sections to make sure the budgeted amount of energy is available. It is not their job to question where or how it is being used. For example, in the thermal section, condensate from one of the operations is being contaminated. The Technical Director, instead of having authority to pressure the user to correct the problem that is causing the contamination, wants to be able to detect the contaminant so he can dump the condensate.

There does not appear to be any effort to analyze processes determining where energy is being used inefficiently. CCC has, however, initiated a request for proposal to Kellog to modify the ammonia plant to improve efficiency and increase production. A similar plant was built in Romania by Kellog, and one of Craiova's ammonia plants was built under license.

The company is in the process of privatizing, and has made some efforts to reorganize the management structure, but much more needs to be done. The way the plant is organized does not emphasize the internal identification and development of energy conservation projects.

2.0 Plant Energy Profile

2.1 Energy Consumption Data

Electrical data has been gathered for the years 1986 - 1990 inclusive. It has been plotted to show variety of information on both power and energy by day, by month, and by year for plant total and by product.

Total electrical energy consumed by year since 1986 is in *Table 1.*

Table 1. Annual Electricity Consumption

Year	Purchased Electricity (MWh)	Generated Electricity (MWh)
1986	1,306,863	16,002
1987	1,242,603	13,683
1988	1,278,864	9,744
1989	1,226,334	11,319
1990	959,226	6,886

In 1990, average steam production was 235 metric tons/hour, and average purchased steam was 540 metric tons/hour. Similar figures for previous years were not made available to the audit team.

An analysis of the data reflects the price changes that took place in 1990. Production went down, thereby requiring less electrical energy. In examining the electrical energy requirements per metric ton of product, the results of an oversized plant with little turndown capability becomes readily apparent. This energy index increases significantly with lowered production, thereby creating a spiral of increased fuel costs - primarily natural gas - decreased production, increased product costs, and less money for fuel, thus further decreasing production.

A major effort to reduce energy usage with low-cost projects can have a significant effect on this spiral. However, a large influx of capital is needed both to allow the plant to operate efficiently on a graduated production scale, and to implement the energy management projects necessary to use energy more efficiently.

2.2 Energy Intensive Products

From the electrical data, it was determined that the oxygen and acetylene are the most energy intensive products as far as electrical energy was concerned. There is an excellent possibility for reduction of energy use through focussing on electrical equipment in these parts of the plant. From a discussion of boiler operation, it is clear that the plant's four boilers also offer an immediate opportunity for a low-cost impact on energy use.

3.0 Audit Description

3.1 General Information

The first day was spent in a discussion of thermal and electrical energy production and problems associated with the equipment. Most of the problems were beyond the scope of this project, but are of value for a complete understanding of the problems the plant faces in the efficient utilization of energy.

In the thermal area four problem areas were discussed:

1. Steam pressure is reduced from 36 bar and 450 °C to 15 bar and 250 °C. The present equipment was built in Sweden and is many years old. Neither pressure nor temperature is accurately reduced.

2. The need for an on-line combustion analyzer was discussed.

3. One condensate line on occasion returns condensate that is contaminated. The need for a Ph meter and a conductivity meter was indicated so the contaminated condensate could be rejected.

4. Meters are needed for measuring oil and natural gas to the boilers.

In the electrical area, the need for metering and control systems was discussed. In addition, plant personnel expressed the need for specialized equipment and materials they did not have access to, because of prior restrictions on imports and now because of lack of foreign currency. The audit equipment was demonstrated to the staff of both the electrical and thermal engineering sections.

3.2 Areas Audited

The boilers were selected for combustion testing, based on experience in other plants, where high excess air was found. Plant personnel stated that twice each year they conduct measurements and energy balances for each boiler at different loads. There is no continuous monitoring of the combustion gas. Daily regulation is made by visual observation, and lab analysis occurs once per month.

Two natural gas and one residual oil boiler were operating at the time of our audit. Each boiler was operating at about 47 metric tons/hour, 36 bar, and 450 °C.

Condensate loss was audited. Staff reported a desire to monitor one condensate line that became contaminated occasionally from the process. Their intention is to dump the condensate when it is contaminated.

Two 12,000 kW air compressors in the oxygen plant receive air from intakes located either 400 or 1800 meters from the plant because of contaminated air around the plant. A calculation showing how much this was costing per year seemed in order.

Two 5,000 kW rotary screw compressors in the acetylene plant were reported to be operating at about 10% capacity. These compressors are designed for throttling in the range from 100% to 70%. Further analysis of this was done. These compressors use approximately 30% of total plant electric power at the current reduced production level.

3.3 Audit Methodology

The combustion analyzer and the digital and infrared thermometers were used to check combustion gas in the boilers.

Two gas operated and one residual oil boiler were operating, each at about 45 metric tons/hour, 36 bar, and 450 °C. They are rated at 50 metric tons/hr.

The first test was on the gas boiler, near the discharge to the stack. Excess air was so high that air leaks in the system were suspected. The test was performed at a port upstream of the air preheater, where excess air was the same.

The operator closed the combustion air damper and continued taking readings until combustion air dropped from over 200% to around 84%. Testing was discontinued at that point when it was demonstrated that the system could be tuned.

The residual oil boiler test showed about 300% excess air. Attempts to adjust the combustion air did not affect the amount of excess air. Preliminary analysis indicated the induction fan to be so large that even with the damper totally closed, air was excessive.

Because of high voltages in the compression sections, the audit team had to rely on information from operators and nameplate data in order to do rough calculations. A power analyzer such as a Dranetz with the necessary current transformers would provide accurate information for these as well as other pieces of equipment.

4.0 Summary of Results

4.1 General Summary

A summary of the potential savings is given below in *Table 2.* It must be pointed out that in the short time allotted for the audit, complete information on all the systems studied could not be obtained, particularly on the compressors. However, the purpose is to show the potential for these and similar projects.

Table 2. Potential Savings

Energy Improvement	Annual Savings-Lei	Annual Savings-$*	Energy Savings
Gas fired boiler tune up	10,909,627	311,704	3,896,000 m^3 of gas
Oil fired boiler tune up	34,987,253	999,637	7,289 metric tons of oil
Condensate return	9,498,978	271,399	17,923 Gcal of steam
Move air intake closer	22,385,600	639,589	13,168,000 kWh of electricity
Unload rotary screw comp.	6,624,238	189,265	3,896,640 kWh of electricity

* Calculated at 35 lei/$.

Calculations for the above projects are given in Appendix A.

4.2 Recommended Immediate Actions

1. Use the combustion analyzer and digital thermometer provided by this project to adjust the combustion air in the four boilers, and other combustion equipment throughout the facility.

2. Increase the quantity of condensate return by first investigating the cause of the contamination, and attempting to fix the cause.

3. With the electrical analysis equipment and PC computer, analyze the operation of both air and acetylene compressors in an effort to reduce their electrical consumption during periods of low production.

4. Establish an energy management program with emphasis on identifying low-cost energy projects.

4.3 Recommended Equipment

For immediate action, the following equipment should be made available to the plant as part of this project:

1. Combustion Analyzer - Similar to the one used by project team.

   This was the principal piece of equipment used to determine that the boilers were operating with as much as 300% excess air. The plant will use the analyzer to further tune the boilers to the correct setting, which will result in the savings projected for boiler tune up.

   Estimated Cost $5,300

2. Heat Spy - 0 - 1000 °C range

   The heat spy has uses in both the electrical and thermal department. Checks can be made on furnace wall temperature, steam pipe insulation, and electrical terminals. It is an excellent tool to determine stack wall temperatures for potential corrosion from sulfur condensation.

   Estimated Cost $2,200

3. Digital Thermometer - Similar to one used by the audit team.

   It is common to measure stack temperature at the point where combustion gas samples are taken. The digital thermometer was used for this as part of the boiler tune up.

   Estimated Cost $700

4. AC Power Analyzer - Dranetz or similar unit.

   The preliminary analysis of potential savings from an analysis of the two compressors cannot be ascertained without a knowledge of the electrical characteristics of the motors at different loads. This is but one of the many uses for this piece of equipment.

   Estimated Cost $5,700

5. PC computer/Printer/Software (1 set) - desktop unit with color monitor for running WP, QPRO, FASAR, and for downloading from AC power analyzer.

   This computer is necessary for graphing, analyzing, and reporting of energy usages from both the AC power analyzer and other metering devices.

   Estimated Cost $3,100

6. Natural Gas Meter - Pipe diameter 300 mm, Maximum flow 20,000 m^3/hr, Temperature 20° C, Pressure 2 bar.

   Estimated Cost $3,900

7. Steam Meter - Pipe diameter 300 mm, Maximum flow 50 metric tons/hour, Temperature 450 °C, Pressure 35 bar.

   Estimated Cost $4,800

8. Oil Flow Meter - Pipe diameter 100 mm, Maximum flow 16 metric tons/hour, Temperature 130 °C, Pressure 32 bar.

   Estimated Cost $4,400

   The three meters listed above will provide the necessary information for calculating overall boiler efficiency, confirming billing from the vendor, and reporting for further analysis of energy consumed per unit of product.

9. Multimeter - similar to one used by team.

   The multimeter is an all purpose instrument for quick analysis of low voltage equipment.

   Estimated Cost $400

4.4 Recommended Long-Term Actions

The following are recommended long-term actions for the plant.

1. Add oxygen combustion control units to all boilers.

2. Add metering to oil, natural gas, and steam lines.

3. Establish a computer control system for dispatching electrical energy.

4. Initiate a study of processes to determine most efficient method of operation during periods of low production.

4.5 Follow-up Actions

1. Deliver equipment to plant, and train personnel on its use.

2. At the end of a reasonable period, 3-4 weeks, request a report from plant personnel on results, particularly with respect to the recommended immediate action list above.

5.0 Plant Management/Organization

5.1 Findings

The company is in the process of changing over from a centralized production unit to a private enterprise. Some attempts have already been made to change the organizational structure, but nothing has been finalized. It is obvious that a major effort should be made to provide assistance. The present management team is basically technical, therefore the complex needs an energy management staff with skills in energy management to address the energy needs and promote energy conservation for a large complex such as Chimic Combinatul.

5.2 Recommended Actions

The company could benefit from assistance from experienced free enterprise management consultants. Included in this organizational restructuring should be an energy management program, encompassing an energy manager at the corporate level, an energy policy, coordinators in each section of the plant, and a comprehensive training program to make the whole process work.

5.3 Supplementary Information

Meeting with Mr. Alexandru Marinescu, Inspector General, MRI, and Professor Mirceu Ton of the University of Craiova led to two additional methods of technical assistance that could be explored. First, under the leadership of these two men, a technical society called Society for the Optimization of Power Consumption in Romania has been organized. In June, they plan to have their first national meeting in Craiova. The possibility of a technical relationship with the U.S. Association of Energy Engineers was discussed. The consultant will pursue this with the Executive Director of AEE. Second, as a result of the meeting with Professor Ton, a meeting was set up with Dr. Mircea Ionescu, Rector of the University of Craiova. At this meeting, we discussed a possible cooperative arrangement with Virginia Polytechnic Institute & State University. The consultant will also explore this further.

6.0 Implementation Phase

6.1 Summary

The implementation phase at Combinatul Craiova Plant started on Monday August 12 and was completed on Friday August 16, 1991. The operation of all portable equipment was briefly demonstrated. The functions, installation procedures, and installation locations of the three fixed flow meters were described. Based on plant observations and discussions with electrical and thermal managers, the audit team believes that all of the equipment will be used to its utmost capability. The facility needs much more monitoring equipment. With the changing economic condition of the company, this equipment may be installed in the near future. Potential for conservation, either through change in equipment, control or integration exists in the many process areas not visited. The following near-term energy conservation activities are envisioned:

- The facility has nine 110 kV substations to distribute electrical power to the entire plant. The present power distribution control and metering equipment was built in the 1960s and needs to be replaced.

- The electrical system manager supplied operating parameters and requested a quotation on future expansion of the nine substations to 400 channels. This request needs follow-up but is beyond the scope of the present program. Electrical monitoring to meet the needs of the nine substations could be envisioned as a fixed power analyzer (Dranetz or others) with a master board capable of accepting nine three-phase inputs to perform analysis and storage.

- Power data recorded for two centrifugal compressors in the Oxygen Plant and two rotary compressors in the Acetylene plant shows a total of about 22 MW. This power is significant and the potential for energy saving is great. The process and equipment in these two areas need to be studied for possible retrofit and operating cost reduction.

- The recovery boiler using waste gases with a heating value of about 3000 kcal/m^3 needs a gas chromatograph with a built-in calorimeter. Either a retrofit of this boiler or a new boiler is expected to be in operation by this October.

- The condensate return from some of the processes is contaminated with process fluids. This hot condensate is wasted when condensate control shows traces of contamination. The manager of thermal systems requested help in solving this problem either by eliminating the source of the leak or providing condensate waste heat recovery. This needs to be fully investigated as over 200 cubic meters of natural gas per hour is wasted. Energy savings are calculated to be about 1,780,000 kcal/yr assuming operation of 6000 hr/yr. This corresponds to a savings of about 3,360,000 lei/yr.

- Management requested help in developing an organizational chart for energy management staff, and a description of the qualifications for the energy management director. Lack of high-level management skill and experience in personnel reorganization has led to apprehension about the results.

6.2 In-Country Draft Audit Report Review

Several topics were discussed including text accuracy and the savings calculations given in the appendix. The report appeared to recommend replacing the existing management team with new, skilled managers. The audit team attempted to clarify this section and explained that the report's overall recommendations were the development of an energy management team with skilled staff to address energy issues.

The savings for centrifugal air compressors in the oxygen plant and rotary screw compressors in the acetylene plant may be somewhat lower than the values shown in the calculations. New data recorded with the power analyzer, as well as additional information obtained about the inter-cooler for the rotary compressors and the four 100 kW blowers supplying air to the centrifugal compressors under a positive pressure, indicates the savings are not as high as shown in the appendix. The lower savings should not negate the recommendation to move the centrifugal air compressor's suction mufflers and filters to the top or the side of the oxygen plant. The 1800 meter suction air duct requires about 400 kW power to overcome the pressure losses. This retrofit will reduce contaminated air around the oxygen plant and eliminate the need for most of the 400 kW motors for the air blowers. The rotary air compressors are efficient when operating at full capacity. The new rotary air compressor models are equipped with an on-line/off-line controller. At relatively low capacity, the compressor will be taken off line by de-pressurizing the discharge accumulator, thereby reducing the power consumption to about 22% of the initial value rather than 70% without this control.

6.3 Energy Efficiency Measures Adopted By The Facility

Several conservation projects are in either the planning or construction phase, but had not been completed at the time of the implementation phase. One of the projects will shut down Ammonia plant #1. Management estimated that 45 MW electric power and about 100 metric tons/hr steam will be saved by this act. A recovery boiler designed to use the residual gases from various processes, especially acetylene, is expected to be completed by this October. Management estimated the heating value of the residual gases at 3000 Kcal per cubic meter. A total of about 15,000 cubic meters per hour may be recovered.

6.4 Management Results

No changes in the management structure have yet been made. This is due to two factors:

1. Existing management does not have the experience to form an organizational structure to address energy management needs

2. The activity involving privatization issues has superseded other corporate matters.

The management requested assistance in developing a new organizational chart. The plant management has many questions regarding appropriate qualifications of the energy management staff and their interaction with the thermal, electrical, production, and corporate managers. They have the desire to form an energy management staff but are apprehensive about the results of so many changes, including privatization. They require expert consultation to revise the plant organizational structure.

6.5 Implementation Plan

Equipment

The two most important pieces of energy saving monitoring equipment are the Enerac 2000 combustion analyzer and the Dranetz electric power analyzer. The PC computer, multimeter, infrared digital thermometer, and hand-held digital thermometer are supporting instruments for the two analyzers. The on-line gas, steam and oil flow meters will be installed on one 50 metric ton boiler burning either oil or natural gas. These three fixed instruments combined with the portable instruments will provide a complete energy and material balance for the boiler, including evaluation of combustion, boiler jacket losses, boiler feed pumps, and forced and induced draft.

At the time of the plant visit (Aug. 12 - 16), all of the fixed equipment had not arrived at the plant. Therefore, no installation work could be done. The audit team visited the boiler where the equipment will be installed to explain the type and capability of the equipment. Installation procedures and location were discussed as well as the recommended installation location for the Masstrol flow computers. At this time, compatibility of the fixed equipment with the boiler capacity, mating flanges, gaskets, and the associated piping is not known.

The audit team demonstrated the operation of the power analyzer and transferred data stored in the power analyzer to the PC. Data was recorded and transferred to the PC from a 12 MW centrifugal air compressor in the oxygen plant and from a 5 MW rotary compressor in the Acetylene plant. The results were discussed and recommendations were made for future data acquisition.

The electrical staff and the managers were pleased with the performance of the power analyzer in combination with the PC. They intend to use the analyzer on the majority of the electrical equipment to analyze performance and determine operational peculiarities. The plot of power and power factor (PF) as a function of operating time is a useful tool for pointing out operational inefficiencies and peculiarities. At the time of the implementation visit, time data could not be automatically transferred to the PC because of a missing adapter, but the staff planned to transfer data manually from the power analyzer hard copier until the adapter arrives.

Because the probe for the plant's Enerac 2000 was lost by the shipping company, the Enerac 2000 operation sequence and capability were demonstrated with a probe borrowed from the Ministry. The Enerac 2000 software was already in the computer. The plant also needed an RS-232 cable so that combustion data from the analyzer could be transfered to the computer. The Ministry requested the borrowed probe's return, so the analyzer could not be used until a replacement probe arrived. Once the Enerac was fully operational, the staff planned to prepare a data log sheet, perform combustion tests and record combustion data for analysis.

6.6 Expected Energy Savings

Expected energy savings predictions for large and complex plants such as Combinatul Chimic are difficult to determine. Due to the wide range of operating parameters and inefficiencies that could be corrected with this equipment, approximate figures were used to determine savings. The use of the fixed equipment, the combustion analyzer, and the supporting equipment in the 50 metric ton/hour boiler will result in at least a 2% efficiency improvement. This will result in savings of about 98 m^3 of natural gas per hour. Assuming 6000 hours per year operating at full load capacity, the annual natural gas savings can be calculated at over 591,000 m^3. This corresponds to a cost reduction of about 1,650,000 lei/yr based on a natural gas cost of 2.8 lei/m^3.

The savings for electrical energy follow similar reasoning. In the oxygen plant, Chimic operates at least two centrifugal compressors rated at 12 MW each. The Dranetz power analyzer shows one of the compressors drawing approximately 7.25 MW of power. Also, two rotary compressors rated at 5 MW each are operating in the Acetylene plant. The Dranetz power analyzer recorded a power draw of approximately 3.6 MW. The total actual power draw of the four compressors is therefore 21.7 MW. A variety of low-cost improvements could reduce the power draw by about 2%. These include cleaning the suction filters, operating the rotary compressors at full capacity, or setting the surge control for the centrifugal compressors at the lowest set point possible. A 2% reduction corresponds to a 434 kW power reduction. Assuming 6000 hours of operation per year, this corresponds to an electrical energy saving of 2,604,000 kWh per year. With electricity cost of 2 lei/kWh, the operating cost reduction would be approximately 5,208,000 lei/yr. This cost reduction is considerably higher than the cost of all the equipment purchased by the USAID program for the Combinatul Chimic Craiova Plant.

APPENDIX A
Energy Conservation Calculations

Boiler Efficiency Improvement

Tests were conducted on two boilers: a natural gas operated unit and a residual oil (equivalent to #6) operated unit.

Samples were drawn from the discharge of the boiler between the economizer coil and the air preheater. The results for the natural gas operated boiler are given below.

A. Natural Gas Operated Boiler

Test #	Oxygen %	Carbon Dioxide %	Excess Air %	Temperature °C	Loss %	
1	14.2	3.8	183	160	26.9	
2	14.4	3.8	191	160	27.4	
3	14.8	3.4	219	160	29.1	
4	14.9	3.4	219	160	29.1	Average
5	14.7	3.5	214	160	28.8 /	28.23

Since excess air was too high, it was decided to close the combustion air damper.

6	14.1	4.1	187	160	27.1
7	10.6	5.9	92	160	21.3
8	10.3	6.1	84	160	20.8 Stabilized

This test was terminated because of good improvement in combustion efficiency.

B. Residual Oil (equivalent to #6)

9	15.0	4.7	247	200	36.1
10	16.0	3.9	303	200	40.0

This test was terminated because the induced fan discharge damper was fully closed and the excess air could not be reduced.

The 160 kW induced fan is oversized for this boiler.

Calculations:

As can be seen, the change in the combustion air damper, using the combustion analyzer as a guide, improved the efficiency by about 7.4%. The constant temperature for both boilers is the reported temperature by the boiler operator. Since this is a comparison, the actual temperature anywhere in the boiler would give the same result.

This stack loss or combustion efficiency can be further improved by air/fuel adjustment or burner cleanup.

Condensate Leak

The Plant has a large number of condensate leaks. These leaks are through valve packing, pump seals, corroded pipes, leaky valves etc.

The most important leak is the contaminated condensate returning from some processes. The Ph level and conductivity are being monitored continuously. When the Ph level and conductivity become unacceptable the entire condensate will be blown off.

At the time of the site visit, two boilers were operating at about 45 metric tons/hour. It is also reported that much of the condensate does not return. Because of these factors the following assumptions were made:

25% of the condensate is lost	= 22,500 kg/hr
Deaerator pressure	= 1.5 bar
Enthalpy of the hot water	= 112.4 kcal/kg
Enthalpy of the city water	= 12.8 kcal/kg
Annual hours of operation	= 8,000 hr/yr
Annual energy loss	= 17,923 Gcal/yr
Average unit cost	= 530 lei/Gcal
Annual cost	= 9,498,978 lei/yr
Annual cost (official exchange rate)	= 271,399 $/yr

Note: The cost does not include cost of pumping, water treatment, and sewer charge.

Note also that this is a demonstration of how a 25% condensate loss becomes very costly. Experience shows attractive payback for repairing condensate leaks.

Oxygen Plant Compressors

The oxygen plant has three 12 MW three stage centrifugal compressors and one 4000 kW outside unit which was not operating during the visit. It is reported that only two 12 MW machines are operating at part load because of low capacity production.

The turndown capabilities of the two centrifugal compressors are 77% to 80%. If air demand falls below 77%, the blow off valve opens to prevent compressor surge. A rough measurement in the substation #2 showed the kW power draw of one of the compressors to be about 77% or over 9300 kW. There is no indication that the compressor was blowing off at this time.

It is reported that the air intakes for the compressors are either 400 meters or 1000 meters away, located in two opposite directions from the Oxygen plant. This is because of air contamination near the oxygen plant. When wind direction changes, air intake must also be changed. It is reported that the discharge pressures of the compressors fall in the range 5.5 to 8 bar. This fluctuation may be due to wind direction.

Assume the following:

Compressor operates at 79.5% capacity with the following parameters:

Air delivery (standard 68 °C, 1.01 bar, 55% relative humidity)	95,400 m^3/hr
Delivery to prevent surge	79.5%
Actual delivery	75,843 m^3/hr
Intake pressure (absolute)	0.97 bar
Discharge pressure (absolute)	10.00 bar
Number of stages	3 stage
Pressure ratio per stage	2.22
Motor efficiency	90%
Isentropic efficiency	82%
Coupling efficiency	82%
Power draw	9,366 kW

Assume excess pressure drop in the suction line causing the discharge pressure to fall. One can calculate the power reduction by maintaining the lower discharge pressure with a lower pressure drop. With the above parameters, calculations show the following:

Absolute Discharge Pressure (bar)	Absolute Intake Pressure (bar)	Differential Pressure (bar)	Power (kW)	Power Reduction (kW)	Cost Reduction (lei/yr)	Cost Reduction ($/yr)
10	0.97	0.0167	9366	0	00	00
9.5	0.8686	0.1181	8726	640	8704000	248686
8.5	0.7567	0.2300	8250	1116	15177600	433646
7.5	0.6674	0.3193	7720	1646	22385600	639589

Hours of operation: 8,000 hr/yr
Unit cost: 1.7 lei/yr

Note: This is an estimate showing a trend for power requirement when intake pressure drop increases. To evaluate the system accurately, more operating parameters need to be included.

Boilers

The residual boiler needs some modifications to reduce the size of both the induced and forced blowers. The boiler efficiency can be improved by about 20% by reducing the excess air, re-sizing the induced or forced blowers, and improving the mixing and atomization.

Assume the following:

Boiler capacity	45 metric ton/hr
Boiler pressure	36 bar
Superheated temperature	450 °C
Condensate return	50%
Deareator pressure	1.5 bar
Boiler steam energy savings	3,316,500 kcal/hr
Natural Gas Consumption savings	487 m^3/hr
Unit cost	2.8 lei/m^3
Cost reduction	1,364 lei/hr
Assume annual hours of operation	8,000 hr/yr
Annual savings	10,909,627 lei/yr
Annual savings (at official exchange rate)	311,704 $/yr

Residual Boiler

For 15% boiler improvement

The Oil Consumption Reduction	911 kg/hr
Unit Cost	4,800 lei/metric ton
Annual cost saving	34,987,253 lei/yr
Annual savings (at official exchange rate)	999,636 $/yr

Note: These calculations are for demonstration to show the high penalty associated with operating boilers with high excess air. It is expected that the correction would have been made during the periodical inspection and the combustion gas analysis.

Rotary Screw Compressors

In the Acetlene plant, there are two rotary screw compressors. These compressors are two stage and rated at about 5000 kW each.

Rotary compressors will operate efficiently at the rated capacity. The efficiency drops significantly at part load or with no load.

During the visit it was found the compressors are operating at about 10% capacity. Calculations below show the penalty associated with these compressors operated at 10% capacity.

The following is reported or assumed:

Compressor rated or nameplate data	5,000 kW
Nominal supply voltage	6,000 V
Nominal current draw	460 amp
Assume power factor	0.85
Load factor	0.81
Calculated power draw	4059 kW

These compressors are controlled with inlet throttling. With inlet throttling control, the turndown ranges from 100% to about 70%. This means the compressor will deliver 100% of the capacity with 100% power. However, if it is not unloaded it will use 70% of the power for 0% capacity. The relationship between flow and power is nearly a straight line.

During the visit it was reported that the compressor was operating with 10% capacity drawing 340 amps.

Actual capacity	10%
Actual current draw	350 amp
Actual power draw	3,000 kW
This results in a load of	74%
The straight line relationship will give	73%

One method to solve the turndown problem is to unload the compressor. The unloading requires a receiver with pressure let down capability. When compressor is not needed, inlet valve closes and the receiver pressure falls to atmospheric, requiring only 22% of the power.

To calculate the economic impact of the turndown control, assume the following:

Existing Time & Capacity				Proposed Time & Capacity			
% Time	% Capacity	fraction	Annual Energy kWh	% Time	% Capacity	fraction	Annual Energy kWh
25	100	0.25	8,118,000	50	100	0.50	16,236,000
25	75	0.19	7,509,150	25	50	0.13	6,900,300
25	50	0.13	6,900,300	25	Unloaded	0.00	1,785,960
25	25	0.06	6,291,450				
100		0.625	28,818,900	100		0.625	24,922,260

Results:

Maintaining the same capacity and unloading the compressor for 25% of the time (2000 hours/yr), the savings are:

Annual kWh saving	3,896,640 kWh/yr
Unit cost	1.7 lei/yr
Annual bill reduction	6,624,288 lei/kWh
Annual bill reduction (using official exchange rate)	189,265 $/yr

Note: These calculations are preliminary only.

APPENDIX B
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 CelsiusT [°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