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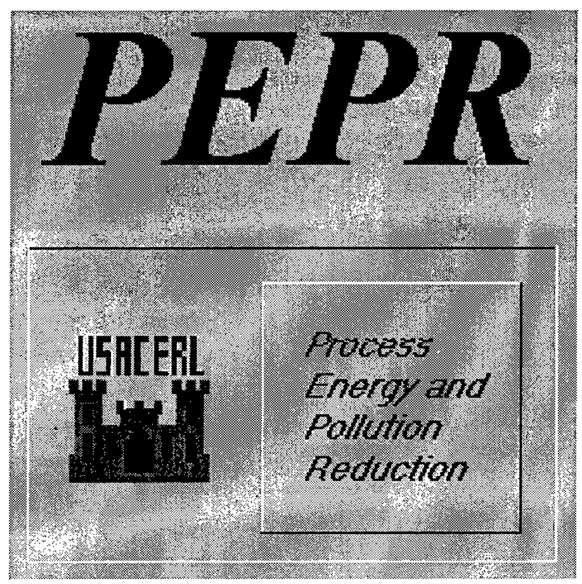
Development of the Process Energy and Pollution Reduction (PEPR) Analysis Tool

by
Mike C.J. Lin, Malcolm Fraser, and Robert Lorand

Department of Defense (DOD) industrial facilities consume large amounts of energy and emit significant quantities of air pollutants. Recent Executive Orders issued by the President set goals for increased energy efficiency and reduced emissions that must be met by these industrial facilities. To help address these needs, the U.S. Army Construction Engineering Research Laboratories (USACERL) has initiated programs to: (1) develop a Process Energy and Pollution Reduction (PEPR) screening tool that can provide energy and emissions evaluations, and (2) identify conservation opportunities for reduced energy consumption and toxic air emissions, via energy efficiency and operational improvements.

An evaluation of the industrial operations at Army Materiel Command (AMC) installations identified five energy-intensive industrial processes for further analysis. Energy conservation and emission reduction opportunities were identified. Energy requirements and emissions were quantified for the alternate technologies and used to estimate total energy usage and emissions for the revised processes. As an aid for rapidly screening these energy conservation opportunities (ECOs) throughout the DOD industrial facilities, a general-purpose PEPR software tool was developed to link the energy/emissions evaluation routines for the selected processes with the ECOs.



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1 Introduction

1.1 Background

Defense Energy Program Policy Memorandum (DEPPM) 91-2 and Executive Order 12759 assign energy efficiency goals for Federal facilities for Fiscal Year 2000 (FY00) as compared to an FY85 base year. In particular, each Department of Defense (DOD) component is directed to prescribe policies and establish appropriate measures of energy efficiency under which the aggregate of its industrial energy-consuming facilities will increase energy efficiency by at least 20 percent in FY00 in comparison to FY85. On 8 March 1994, Vice President Al Gore announced that President Clinton had signed Executive Order 12902, which calls for an increased energy efficiency in Federal industrial facilities by at least 20 percent by 2005 as compared with FY90, and which also requires agencies to implement all cost-effective water conservation projects (Section 302(b)). It also increases the energy savings requirement for agencies to 30 percent by 2005 as compared with FY85 in Btu per gross square foot (Section 301(a)).

In addition, Title III of the Clean Air Act Amendments of 1990 directs the U.S. Environmental Protection Agency (USEPA) to establish criteria controlling the emissions of 189 air toxic chemicals. The majority of these air toxic chemicals originate from industrial activities. In 1992, the USEPA began developing regulations governing the control of emissions of these chemicals from industrial activities for 41 source categories. Further development of regulations will continue through the year 2000 for the remaining 250 source categories. As DOD industrial operations emit significant quantities of air pollutants, including toxic emissions, DOD's industrial energy-consuming facilities must develop strategies to meet these toxic emissions reduction goals.

To address these needs, the U.S. Army Construction Engineering Research Laboratories (USACERL) has initiated a program to develop a strategy to help DOD facilities cost effectively meet the specified Federal facility energy conservation goals and the toxic emission reduction goals of the 1990 Clean Air Act Amendments.

1.2 Objectives

The objectives of this work were:

1. To develop a Process Energy and Pollution Reduction (PEPR) tool that can provide energy and emissions evaluations.
2. To identify opportunities whereby reduced energy consumption, achieved through energy efficiency and operational improvements, can simultaneously bring about significant reductions of toxic air emissions.

1.3 Approach

1. The industrial operations at Army Materiel Command (AMC) installations were examined and characterized in terms of process energy consumption and toxic emissions, based on data from previous studies. Data on AMC facilities were gathered from previously published reports. These data were examined and evaluated for the purpose of selecting five energy-intensive industrial processes for further analysis.
2. A routine was developed to evaluate energy consumption and emissions for processes. The functions of the routine were to:
   a. provide appropriate procedures for conducting energy and emissions evaluations
   b. estimate energy consumption and toxics emissions
   c. furnish relationships among production, energy, and pollution.
3. Energy conservation and emission reduction opportunities and associated appropriate alternate technologies, were compiled for the five processes. These opportunities were identified by reviewing the literature for new technologies and by consulting with experts who evaluated the processes of interest. Energy requirements and emissions were quantified for the alternate technologies, and were used to estimate total energy usage and emissions for the revised process. Data on capital investment were also compiled for the alternate technologies proposed, and a methodology was developed to evaluate the return on the investment in alternate technologies with regard to savings in energy costs and pollution control.
4. Software was developed to link the energy/emissions evaluation routine with the list of opportunities developed. This software tool was developed for general use in DOD industrial facilities performing similar operations; the tool was based on the specific data on processes and operations, and on the energy and pollution reduction technologies. However, it was developed as a flexible general-purpose tool with the ability to accept additional process information and alternate technologies in its data base.

In a final task, technical documentation was prepared, including a user's manual for the software tool. This manual describes the system requirements and the program operations for the software. This technical report describing the information derived from the performance of the work was also prepared.

1.4 System Requirements

The system was developed using Microsoft FoxPro Version 2.6 for Windows. FoxPro is a Relational Data Base Management System (RDBMS) with a built-in programming language that allows the development of custom applications. PEPR requires an IBM PC or compatible with an 80386 or higher microprocessor. It also requires approximately 8 megabytes of disk space as well as at least 8 megabytes of RAM. The system was developed for a Windows environment and requires Microsoft Windows 3.1 or higher to run properly. It also was developed for use with monitors having VGA resolution. If the PEPR program is used with super VGA resolution, the program screen will not fit the monitor screen properly. In this case, the monitor resolution must be set up for VGA.

1.5 Scope

This study is part of the Strategic Environmental Research and Development Program (SERDP). The project seeks to develop tools to help DOD industrial operators make informed decisions on whether to change/modify processes or to adopt new technology to achieve the energy and environmental goals. In addition to energy and environmental engineering, group dynamics and human potential research techniques are included in the tool development package. This project attempts to extend the mass and energy flow modeling concepts to industrial activities and their potential air toxic emissions. Initial efforts are focused on developing a level-I PEPR analysis tool that will help installations prepare a prioritized implementation plan to meet the required energy and environmental goals. The product developed from this project could be used by all DOD industrial operations. It is also applicable to commercial industries of similar operations.

The scope of the effort concerned with the collection of process data was limited to five energy-intensive processes with significant potential for being common to a number of Army bases. The collection of data and descriptive information on the five processes was limited to previously published reports and other literature. In addition, the energy conservation opportunities (ECOs) identified are limited to these five processes, as are the process data in the data base in this initial version of PEPR.

The basic structure of the PEPR software tool was developed to accommodate the most detailed and comprehensive set of process and emissions data, but the tool does not require the greatest amount of detail possible to accomplish its main purpose—which is to be a screening tool. PEPR is not a process simulator, although it does contain basic analytical routines and calculations designed to aid users at the process engineering level to analyze their data. PEPR does a complete and accurate analysis with data that are specific and sufficiently complete for a given situation. PEPR was designed to be flexible and easily expandable. Data on other processes and ECOs can be inserted easily into PEPR's data bases for analysis. Other routines can be developed and included within the tool to help the user develop input data for a particular process.

1.6 Mode of Technology Transfer

It is anticipated that the information presented in this report will be disseminated in the Army Research, Development, and Acquisition Bulletin. It is recommended that the energy/emission review results obtained and the description of the software tool development be presented at the Industrial Energy Technology Conference. The PEPR program may be obtained by contacting the USACERL Industrial Operations Division at 800/872-2375, ext. 3487. The program will be transferred to Army Materiel Command Headquarters for further distribution.

1.7 Metric Conversion Table

The following metric conversions are provided for standard units of measure used throughout this report:

1 ft	=	0.305 m
1 sq ft	=	0.093 m^2
1 sq in.	=	6.45 cm^2
1 cu ft	=	0.028 m^3
1 lb	=	0.453 kg
1 gal	=	3.78 L
1 oz.	=	29.57 mL
1 psi	=	6.89 kPa
°F	=	(°C × 1.8) +32
1 Btu	=	1.055 kJ

2 Army Industrial Facilities

2.1 Facility Types

The primary operator of industrial facilities and, therefore, the primary user of process energy within the Army, is the U.S. Army Materiel Command (AMC). AMC operates directly, or through contract, a number of large facilities across the United States that fall into the following categories: Propellant and Explosive plants; Load, Assemble, and Pack plants; Small Arms Ammunition plants; Ammunition Metal plants; Manufacturing plants; Manufacturing Arsenals; Supply and Maintenance Depots; Supply Depots; Research and Development facilities; and Proving Grounds. They are either Government-owned Government-operated (GOGO), or Government-owned Contractor-operated (GOCO).

2.2 Energy Usage

Table 1 shows the total energy usage at AMC facilities by installation for 1992. Of the top 10 energy-consuming AMC installations, four are arsenals and three are ammunition plants. The processes at these types of facilities should therefore be emphasized in any study of process energy, potential energy conservation measures, and process improvements.

Of the total energy used at each of these AMC facilities, it is difficult to estimate that portion used strictly for process purposes as opposed to the energy used to operate the facility (such as energy used for heating buildings). Neither energy consumed in process equipment nor in building energy consumption is generally metered. Therefore, the proportion of total energy reported for process use is only an estimate.

A recent study by the Institute for Defense Analysis (Institute for Defense Analysis August 1994) attempted to define how much energy consumed at Army Ammunition Plants (AAP) could be considered process energy usage, using Holston AAP as a sample. The study concluded that probably 95 to 96 percent of total energy used was for process use. However, Holston AAP may be an anomaly because, like Radford AAP, it is a Propellant and Explosive plant with highly energy-intensive chemical processes.

Table 1. Total energy usage in AMC facilities (1992).

AMC Rank	Installation Name	Total Energy Mbtu/yr	Total Energy Mbtu/hr	Operator G or C	Process Energy %Pro. Eng	Process Energy Mbtu/hr
1	Aberdeen Proving Ground	2404995	275	G	41	113
2	Redstone Arsenal	1614038	184	G	50	92
3	Holston Army Ammo Plant	1366074	156	C	70	109
4	Rock Island Arsenal	1262472	144	G	39	56
5	Radford Army Ammo Plant	1191737	136	C	68	93
6	Picatinny Arsenal	1053072	120	G	27	32
7	Fort Monmouth	984888	112	G	23	26
8	Lake City Army Ammo Plant	899831	103	C	16	16
9	Red River Army Amm0 Depot	846610	97	G	71	69
10	Pine Bluff Arsenal	728624	83	G	75	62
11	Stratford Army Engine Plant	690761	79	C	—	—
12	Detroit Arsenal	681964	78	G	59	46
13	Tobyhanna Army Depot	675671	77	G	60	—
14	Anniston Army Depot	666293	76	G	36	46
15	Lone Star Army Ammo Plant	659007	75	C	—	27
16	White Sands Missle Range	637172	73	G	39	28
17	Iowa Army Ammo Plant	619304	71	C	19	13
18	Longhorn Army Ammo Plant	572197	65	C	65	42
19	Watervliet Arsenal	570620	65	G	35	23
20	Tooele Army Depot	538745	62	G	21	13
21	Lima Army Tank Plant	476480	54	C	57	31
22	Letterkenny Army Depot	465991	53	G	47	25
23	New Cumberland Army Depot	445310	51	G	61	31
24	Scranton Army Ammo Plant	426246	49	C	42	20
25	Corpus Christi Army Depot	382044	44	G	—	—
26	Mcalister Army Ammo Plant	339480	39	G	57	22
27	Dugway Proving Ground	320519	37	G	15	5
28	Sacramento Army Depot	243054	28	G	62	17
29	Twin Cities Army Ammo Plant	234763	27	C	8	2
30	Joliet Army Ammo Plant	232831	27	C	—	—
31	Milan Army Ammo Plant	221662	25	C	44	11
32	Harry Diamond Lab	220041	25	G	44	11
33	Hawthorne Aap	217319	25	C	48	12
34	Lexington Bluegrass Army Depot	195845	22	G	19	4
35	Kansas Army Ammo Plant	195731	22	C	49	11
36	Pueblo Depot Activity	165994	19	G		—
37	Seneca Army Depot	164946	19	G	42	8
38	Rocky Mountain Arsenal	157631	18	G	24	—
39	Vint Hill Farms Station	151275	17	G	—	—
40	Usa Natick Rd & E Center	148997	17	G	—	4
41	Cameron Station	148435	17	G	—	—
42	Indiana Aap	139164	16	C	48	8
43	Sierra Army Depot	132841	15	G	26	4
44	Yuma Proving Ground	131126	15	G	54	8
45	Louisiana Army Ammo Plant	124905	14	C	75	11

AMC Rank	Installation Name	Total Energy Mbtu/yr	Total Energy Mbtu/hr	Operator G or C	Process Energy %Pro. Eng	Process Energy Mbtu/hr
46	Savannah Depot Activity	122847	14	G	8	1
47	Sunflower Army Ammo Plant	116386	13	C	67	9
48	Materials Technology Lab	108611	12	G	34	—
49	Riverbank Army Ammo Plant	90012	10	C	—	3
50	Mississippi Army Ammo Plant	82040	9	C	—	—
51	Badger Aap	75310	9	C		
52	Newport Army Ammo Plant	67660	8	C	8	1
53	Ravenna Army Ammo Plant	62089	7	C	41	3
54	Jefferson Proving Ground	60447	7	G	16	1
55	Umatilla Depot Activity	30499	3	G	—	—
56	St. Louis Aap	17649	2	C		—
57	Fort Wingate Depot Activity	16780	2	G	80	—
58	Volunteer Army Ammo Plant	13485	2	C	—	1
59	Cornhusker Aap	3178	0	C	—	—
60	Sharpe Army Depot	0	0	G	—	—
	1992 AMC Total	25613698	2924			
	1992 AMC Bases with Estimation of Process Energy				45	1172

A number of energy audits and analyses have been done in the past on AMC facilities. However, most of these studies were aimed at developing an analysis system for managing process energy. The purpose of this analysis system was to determine the response of process energy consumption to changes in levels of mission activity, various conservation efforts, and changes in mission. The basic elements of the analysis system were functional relationships between process energy consumption and production/mission parameters. In these studies, the main objective was to determine the production/mission parameters that exerted significant influence over total process energy consumption, and to determine values for these parameters and coefficients relating them to process energy consumption using regression analysis methods.

A few of the past studies were done to establish process energy inventories to illustrate the "detailed engineering analysis method" for determining process energy consumption.

A more detailed discussion and a listing of past energy studies at Army industrial facilities that attempted to analyze process energy usage follows.

2.3 Overview of Army Industrial Processes

Five energy-intensive Army industrial processes were selected to demonstrate the PEPR software tool for analyzing process energy usage and screening ECOs. It was desired to select candidate processes that were both energy-intensive and common to a number of facilities so that potential ECOs could have a significant aggregate impact on energy use at Army industrial facilities. It was also desired that the selected processes have emissions and air toxics associated with the energy consumption. It was a fundamental assumption for the scope of this project that suitable process data with sufficient detail be available through published reports of prior energy and/or environmental studies of Army industrial facilities.

Available data sources were identified, and the data were collected, compiled, and evaluated for completeness and suitability for the objectives of the project. The data were analyzed for the dual purposes of selecting five processes to put into the PEPR software screening tool, and identifying potential ECOs. This section describes the gathered data sources. The collected data and their evaluation are discussed, and the procedure for selecting the five processes for detailed analysis is described.

2.4 Data Sources and Their Evaluation

2.4.1 Required Data

Developing the PEPR software tool required collecting the following data for each process to be included in the initial PEPR data base:

1. Process block flow diagram
2. Current/planned operating schedules and levels and, for each process step:

    a. Material balance data
    b. Energy consumption data
    c. Air emissions data
    d. Equipment description.

(See Table 2 for a more detailed list of the required data.)

To evaluate and rank-order energy savings opportunities for Army industrial processes in terms of their aggregate total energy impact in all Army industrial facilities, it would have been helpful to have data on the total annual production, by specific product, of the various products produced via these processes at Army industrial facilities, for example, the total production of each munition assembled on

Table 2. Required process energy and emissions data for PEPR screening tool.

a. General information
- process schedule (batch or continuous, operating hours per week, weekdays, shifts, etc.)
- process bottlenecks and hazards
- desired production capacity
- annual production

b. Quantitative process data (for each individual step in the process)
- inputs and outputs of materials
- inputs and outputs of energy, by type (if steam, need pressure and temperature)
- necessary process conditions (pressure, temperature, and residence time)
- quantities of criteria pollutants, by type, uncontrolled and controlled (what type of control)
- hazardous air pollutants (HAP) emissions, by species

c. Process equipment (for each individual step in the process)
- description
- condition
- age
- nameplate capacity
- energy requirements (by type: electricity, fuel, compressed air, steam, cold water, hot air, etc.)
- power consumption
- size of the motor

load, assemble, and pack lines of various types; or the total annual production of explosives, by type, etc. It would also have been helpful to know: (1) how many production lines there are of the various types, and (2) what products are produced at the various candidate facilities of interest. However, this type of information was found to be largely unavailable.

2.4.2 Available Reports

2.4.2.1 Energy Analysis Reports. A series of Energy Engineering Analysis Reports for various facilities were completed in the late 1970s and the early 1980s (AAI Corporation December 1982; GARD, Inc. November 1984, May 1983, and November 1983; Geomet Technologies 20 November 1993; IDA August 1994; Reynolds, Smith, and Hills March 1991; Thompson et al. September 1981 and April 1983; TRW 10 April 1978). Most of these reports are more than 10 years old and, with only a few exceptions, do not contain the detailed energy consumption data and equipment descriptions needed for a comprehensive PEPR analysis.

The primary purpose of many of these energy analysis reports was to analyze total facility energy consumption by using regression analysis to determine the important variables and to develop an equation to predict energy consumption as a function of production level. Since energy consumption at the level of individual processes or process steps is virtually never directly measured or monitored, it should not be surprising that such data do not exist, but rather must be estimated with the aid of equipment specifications and engineering analysis. However, these reports contained little descriptive information on equipment that might have allowed engineering estimations of energy consumption.

2.4.2.2 Air Emissions Inventory Reports. A series of reports are being prepared to develop air emissions inventories at Army industrial facilities. The reports available for use in this project—for Lonestar AAP, Iowa AAP, Radford AAP, Milan AAP, and Holston AAP (Earth Technology Corp November 1993a and 1993b; Geomet Technologies 30 November 1993; Woodward-Clyde Federal Services 23 November 1994 [a and b]) are concerned, however, only with emissions data. There is only a minimal amount of information about production lines per se, and there are no data on process energy usage except for central boilers. These reports typically have some descriptive information regarding process unit operations that are air pollution sources, along with estimated emissions. Air emissions emanating from a pollution source are, for the most part, estimated from data on material usage and accepted emission factors. These emission factors and calculations can be applied to other bases.

2.4.2.3 Reports on Hazardous Waste Minimization Studies. Reports on a number of recent hazardous waste minimization (HAZMIN) studies performed for the Army Materiel Command/Army Production Base Modernization Activity at Picatinny Arsenal were examined as another source of information and data on Army industrial processes. These reports were available for Radford, Longhorn, Lonestar, and Louisiana AAPs; and the electroplating line at Corpus Christi Army Depot (Day and Zimmerman 19 October 1990 [a and b], 27 July 1990, May 1993, 8 February 1991; SAIC September 1992, October 1993, 1 December 1986).

These reports contain descriptions of the processes with emphasis on wastes. They also contain a number of suggestions for process improvements (e.g., for Radford, to use less volatile solvents in propellant formulations [to reduce VOC emissions], or to transition to solventless propellants), but they contain no energy data.

Other studies concerned with waste reduction alternatives and environmental readiness are also listed in the Reference section. However, they also contain little energy data.

2.5 Data Analysis

Table 3 summarizes the data on products and processes, and associated energy and emissions data, gleaned from the collected reports.

Table 3. Data collected on products and processes.

Facility	Product	Description of Process Operations	Block Diagram	Energy Data	Emissions Data
Corpus Christi Army Depot (25)*	Large diverse plating/metal finishing shop producing parts (engines, transmissions, rotors, airframe sections) for helicopter maintenance	Sketchy			
Holston AAP (3)	Chemical support:				
	acetic acid concentration	X	X		
	acetic anhydride -				
	manufacture & refining	X	X		}X
	nitric acid (AOP)	X	X		
	nitric acid concentration	X	X		
	ammonium nitrate	X	X		
	Explosives:				
	RDX (Research Development				
	Explosive - $C_3H_6N_6O_6$)	X	X		
	HMX (High Melting				
	Explosive - $C_4H_8N_8O_8$)	X	X		
Iowa AAP (17)	M106 shells (other sizes as well)	X LAP lines	X	X	X
Lake City AAP (8)	5.56mm:				
	casings		X		
	bullets		X		
	assembly		X		
	(also 7.62mm, 20mm, and 50 cal.)				
	primers		X		
	tracers		X		
	lead styphnate				
Lonestar AAP (15)	Anti-tank mines	Sketchy, apparently similar to other LAP lines			X (need process data to relate to products)
	Personnel mines				
	Cluster bombs				
	Large-caliber artillery shells				
	Other				
	primers				
	fuzes				
	detonators				
	delays				
	tracers				
	grenades				
Longhorn AAP (18)	Pyrotechnic ammunition	Sketchy, apparently similar to other LAP lines			
	illuminators				
	flares				
	signals				

Facility	Product	Description of Process Operations	Block Diagram	Energy Data	Emissions Data
Louisiana AAP (45)*	Metal parts 155mm projectile casings ogives bases M692/M731 ADAM projectiles Claymore mines M112 demolition blocks	Sketchy, apparently similar to other LAP lines			
Milan AAP (31)	Class A (high explosives): 120mm mortars M831, M835, M829 cartridges Class B (propellants)	Not available, apparently similar to other LAP lines			X (need process data to relate to products)
Pine Bluff Arsenal (10)	Smoke grenades	X LAP lines	X		
Radford AAP (5) (some process descriptions and emissions data available via report on Badger AAP)	Chemical support: nitric acid (AOP) acid concentration (NAC-SAC) oleum (SAR) Main processes: nitrocellulose (NC) TNT nitroglycerin (NG) Propellants: single-base propellants (CASBL) multi-base propellants (CAMBL) rocket motors solventless propellants	 X X X X X X X X X	 X X X X X X X X X		}X
Scranton AAP (24)	Artillery casings (various sizes)	X			
Watervliet Arsenal (19)	Mortars Cannon Components				

*Note: number in () indicates rank order in list of AMC facility total energy usage for 1992.

The information on air pollution sources from the five air emissions inventory reports discussed above was examined in an effort to identify common types of process operations at these five bases. Table 4 lists the air emissions sources at the five bases described in these reports. The table has two parts: (1) production processes, which produce identifiable, readily quantified products, and (2) generic operations, which are not necessarily part of a process producing such products. With respect to production processes at these five bases, the table shows that there appears to be little commonality, except for load, assemble, and pack lines, and acid production. On the other hand, many generic operations are performed at all of these bases, but the question of how much energy these operations consume needs to be answered.

To illustrate some differences in total specific energy consumption (total energy consumption per ton of product), some data are available from a report on energy usage at Radford AAP. These data are useful for identifying the more energy-intensive processes at propellants and explosives plants (PEP). These data are shown in Table 5. Chemical support processes (ammonia oxidation process [AOP] for producing nitric acid, nitric acid-sulfuric acid concentrating process [NAC], and sulfuric acid regeneration [SAR]) appear to be the least energy-intensive processes at a PEP. Nitroglycerine consumes relatively little energy as well. On the other hand, nitrocellulose appears to be a good candidate for an energy-intensive process and is described in the Radford report as "the largest single user of steam and electrical energy."

2.6 Process Selection

The evaluation of the available data sources, as described above, showed that they did not contain the necessary process data and information needed to make a process selection/ranking based on energy usage. However, sufficient data were available to give a sense of what energy-consuming processes are common to a number of installations; process commonality was an important consideration for selecting the processes to be included in the initial version of the PEPR software screening tool. It was also desired to select processes that both consume energy and emit pollutants. Finally, discussions were held with AMC and Industrial Operations Command (IOC) to determine what processes would be of greatest interest to base personnel.

In the data evaluation described above in a previous section, the most energy-intensive processes appear to be the chemical processes for producing basic explosives. These processes can involve the production of a great deal of heat with a number of process streams being heated and cooled, especially those involving the production and concentration of nitric and sulfuric acids.

Table 4. Air emissions sources at Army industrial facilities.

Process	Holston	Iowa	Lonestar	Milan	Radford
a. Production Processes					
Nitric and sulfuric acid production	- tail gas from nitric acid absorption column - unreacted NO_x from NAC				- spent-air compressors - sulfuric acid concentrators
Acetic acid and acetic anhydride	uncondensed reactants from distillation columns (vents)				
Explosives (RDX and HMX)	- condenser vent emissions from lacquer preparation - hexamine dust - VOCs from dissolving tank - VOCs and NO_x from wet scrubber vent - VOCs from dissolver-still condenser vent - PM_{10} from bed dryer scrubber - PM_{10} from TNT package system - PM_{10} from TNT kettle scrubber - PM_{10} from product packaging system - VOCs from acid recovery condenser vent				
Nitrocellulose					- drying - fume recovery molecular sieve system - nitrator - boiling tubs
Nitroglycerine					sealed system
Single- and multi-base propellants					- solvent emissions in every process step - solvent recovery system - finishing area - forced-air dryers
Rolled powder					- final mixer - pressing - cutting machines - cutting bays - traying - loading
Loading, assembling, and packing of ammunition and explosives		- mixing/blending - melting/pouring/drying - load/assemble/pack - PM_{10} and HAPs	- mixing/blending - melting/pouring/drying - load/assemble/pack - PM_{10} and HAPs	Fugitive VOC emissions emanating from solvents used in wiping and cleaning	

Process	Holston	Iowa	Lonestar	Milan	Radford
Pyrotechnic mixtures -- Mixer-Granulator-Dryer (MIGRAD) System			VOC emissions collected with a vacuum collection system		
b. Generic Operations					
Abrasive blasting	three machines	one machine			- sandblasting booths - portable units - grinding
Degreasing	cold	small recirculating diptanks	small diptanks	cold	cold and covered
Extrusion/spiral wrap					sawing and spiral wrap operations
Incinerators	two for burning refuse	- explosive waste - contaminated waste - deactivation furnace			- NO_x afterburner - waste propellant (2) - decontamination oven
Laundry		TSP from clothes dryers			
Machine shop				no emissions	
Painting	paint booth and misc.	spray booths	spray booths	spray booth	spray booths
Photoprocessing	- x-ray development - photofilm development			- x-ray development - photofilm development	
Printing		VOC emissions	VOC emissions		
Surface coating					curing and conditioning of teflon-coated items (heat used in ovens)
Waste solvent/oil recovery			batch distillation		
Water and wastewater treatment	- drinking water - sewage - industrial wastewater	primarily sewage treatment	- sewage - industrial wastewater	- drinking water - sewage - industrial wastewater	- drinking water - sewage - industrial wastewater
Welding	PM_{10} and HAP emissions	PM_{10} emissions, as needed basis	PM_{10} emissions	PM_{10} and HAP emissions	- 1/3 in shop - 2/3 in field
Woodworking	- cutting - sanding (no HAPs from pressure-treated wood)	- cutting - sanding (no HAPs from pressure-treated wood)	- cutting - sanding (no HAPs from pressure-treated wood)	- cutting - sanding (no HAPs from pressure-treated wood)	- cutting - sanding (no HAPs from pressure-treated wood)

Table 5. Total specific energy consumption for processes at propellants and explosives plants (Radford AAP) for spring-fall months.

Energy Consumption (per ton of product)	TNT	Nitro-cellulose	Nitro-glycerine	AOP Old	AOP New	NAC-SAC	SAR	Propellants Batch	Propellants CASBL	Rolled Powder
Steam:										
400 psig, lb/ton	10,300								43,200	5,100*
260 psig, lb/ton		1,688	50	192	0	3,000	(2,291)	3,781		
40 psig, lb/ton		23,100						10,600		5,100**
Electricity: kWh/ton	484	1,460	150	209	40	68.7	64	987	4,350	1,080

* Line 1.
** Line 4.

However, these processes can also involve a significant degree of heat and power integration, which is not described in detail in the simple input-output diagrams in the available reports. As a result, the potential complexity of these processes would require extensive analysis to identify and analyze potential ECOs, and to optimize such a process as a whole. In addition, these chemical processes are not very common in Army industrial facilities, being largely confined to Holston and Radford AAPs. Consequently, only one of these purely chemical processes was chosen for the initial version of PEPR.

As the result of these considerations, the following processes were selected for inclusion in the initial version of PEPR:

1. A load, assemble, and pack line
2. A representative process for explosives production (although the processes to produce explosives are specific to each compound—NC, TNT, NG, etc.—and may be carried out at only one installation each, they contain similar steps)
3. Spray painting
4. Electroplating
5. Heat treating (ovens, etc.).

In general, the data that could be collected from the literature on these five processes were not sufficiently detailed for comprehensive PEPR analyses. Where possible, they had to be supplemented with data collected via private communications and contacts with equipment manufacturers. The results of the analyses of these processes are discussed in Chapter 5.

3 The Process Energy and Pollution Reduction Methodology

3.1 Objectives

The overall objective of the Process Energy and Pollution Reduction (PEPR) methodology, as presented and discussed in a workshop sponsored by USACERL at Pine Bluff Arsenal (Smith 21-24 June 1994), is to significantly reduce overall manufacturing cost by optimizing the use of energy at the point of use—the process. The discussion of this methodology in this section is drawn largely from the material presented at this workshop.

PEPR is not simply conventional energy conservation. It is a demand-side approach that focuses on the process energy loads at the end of the energy supply line. PEPR applies specific energy analysis and process innovation techniques that result in a modified or new process for producing the product or service. The underlying foundation of the PEPR approach is to question the current or—in the case of a new design—the proposed operating conditions, practices, and procedures. With respect to emissions and pollution, the PEPR approach is to consider changes in the process to reduce or to even eliminate emissions rather than simply to focus on controlling existing emissions and pollution.

The five basic approaches to save energy costs in manufacturing are:

1. Reduce the unit cost (price) of purchased energy.
2. Improve energy conversion efficiencies; for example, the efficiency in the use of fuel to generate steam or hot water, or the use of electricity to chill water, compress air, or light lights.
3. Conserve energy, passively (by insulating to reduce its loss), or actively (by installing automatic switches or controls to shut off or modulate its use).
4. Recover or recycle waste streams; for example, using exhaust heat, pressure recovery, or vapor recompression.
5. Modify the process by changing operating conditions, procedures, or practices; or by introducing new process energy technology.

The first four approaches involve saving energy in supplying energy to a point of use. That is, each is concerned with energy purchase, conservation, delivery, and recovery (all supply-side strategies). The fifth approach, modifying the process, is the primary goal of the PEPR approach; pursuing this approach can produce savings that exceed the collective benefits of all the others.

Thus, PEPR, in contrast to conventional energy conservation approaches, focuses on demand; it aims to reduce the energy demand at the point of use and change it to a less expensive energy form. Effective PEPR also significantly affects the supply-side energy. The PEPR methodology sometimes appears to be contrary to more established approaches to energy conservation. PEPR concentrates on the *process*, the ultimate demand, while other energy conservation strategies work on *systems*. What is meant by process as opposed to the system? For PEPR, the process is any operation or function in a facility that uses energy. The process is carried out by the system. The system is the collection of equipment that performs the process.

Because of the physical reality of the system, it is easy to think only in terms of revising the system. A system change will often change the process, but PEPR requires a deeper examination of the process and its basic function. The PEPR methodology requires an examination of the purpose of the process, why it operates as it does, and how the ultimate goal might be accomplished better through a change that actually modifies the process. In each case, by focusing on the process, a PEPR analysis leads to ways of reducing the energy inputs required to meet the system's purpose. PEPR seeks a better system and method (process) to achieve the same end.

3.2 Approach

The approach to carrying out a PEPR program involves four phases, described in this chapter: (1) program development, (2) process energy analysis, (3) process energy innovation, and (4) program implementation.

3.2.1 Program Development

The measures taken in this phase include:

1. Performing a facility-wide energy audit
2. Selecting general PEPR targets
3. Preparing a PEPR program outline
4. Securing management support
5. Selecting a PEPR team.

3.2.2 Process Energy Analysis

In this phase, the type, quality, and amounts of energy used and rejected in each target area are determined. In this phase, goals and requirements not related to energy (such as environmental compliance) are reviewed to identify opportunities. Process energy analysis is broken down into three main steps:

1. Quantifying energy use
2. Characterizing energy use
3. Identifying nonenergy goals and constraints.

3.2.3 Process Energy Innovation

In this phase, existing process conditions, procedures, and practices are challenged, as is the basic technology of the existing process. Alternative, low-energy processes that appear to offer competitive advantages are identified and developed. Process energy innovation is broken down into four steps:

1. Challenging the process
2. Structured group brainstorming
3. Compiling and clarifying ideas
4. Developing candidate projects.

3.2.4 Program Implementation

In the final program phase, the best candidates for process changes or alternate technologies are clarified and implemented. Implementation of candidate projects will range from easy procedural changes to more difficult R&D projects. The ideas may require redesign, some degree of pilot testing, and demonstration on a production basis. In this final phase four more steps must be completed to reach the ultimate goal of a modified process that uses less energy:

1. Selecting projects
2. Sequencing and timing projects
3. Developing PEPR program economics
4. Authorizing the program
5. Managing and auditing the program.

3.3 Energy/Emissions Auditing Procedures

The PEPR methodology involves energy and emissions audits, but these audits focus on the process. The differences between more conventional energy audits and PEPR audits are described below.

3.3.1 Conventional Energy Audits

1. Typically involve a thermal team and an electrical team
2. Start in the boiler house and the compressor room
3. Include utility distribution systems
4. Emphasize energy-supply efficiency improvements
5. Look for leaks and heat-loss reductions.

3.3.2 PEPR Process Audits

1. Focus on energy end-use operations
2. Analyze and consider the ways in which energy is *used* rather than how energy is *supplied*
3. Focus on finding ways to use energy more wisely to improve overall process performance
4. Modify or change the process.

From the viewpoint of PEPR methodology, traditional energy audits are deficient in several ways. They start at the wrong end of the energy conduit. Easy targets of traditional energy audits, such as boiler tune-ups, may not be the best use of the audit team's time. Energy end-use areas offer the greatest opportunities. More critical questions concerning energy are: (1) where the steam goes, (2) how steam is used, and (3) whether it is possible to eliminate the need for steam. Finally, audits that start in the boiler house rarely get out to the process.

Like traditional energy audits, PEPR process audits involve three levels of procedures: Level I, an analysis based on a walk-through the plant accounting for perhaps 50 percent of the energy usage with no measurements being involved (2 to 15 work-days of effort); Level II, a shortened in-depth analysis of the process accounting for perhaps 80 percent of the energy usage with some measurements being involved (15 to 70 work-days of effort); and finally Level III, which involves several weeks and 50 to 400 work-days of effort accounting for 95 percent of the energy usage and developing detailed analyses of energy and pollution reduction measures. Table 6 lists the differences between these levels of detail in audits.

Table 6. Definition of Level I, II, and III PEPR process audits.

Characteristic	Level I	Level II	Level III
1. Type	walk-through	short	full
2. % Energy accounted for	50%	80%	95%
3. Duration (days)	1-3	3-7	7-20
4. Audit team (no.)	2-5	5-10	8-20
5. Investment type	expense	capital & expense	capital & expense
6. Measurements	none	some	many
7. Quantify	±40%	±20%	±10%
8. Time spent (%supply/%end use)			
traditional audit	90/10	80/20	80/20
process audit	0/100	10/90	10/90

Source: W. Smith, "Process Energy and Pollution Reduction (PEPR) Workshop," Pine Bluff Arsenal (21-24 June 1994).

3.4 Results

Process improvement and change achieved through the application of the PEPR methodology usually result in significant benefits and an improvement in the competitive position of the process. Typical results are improvement in raw material use, optimization of energy use, increase in product quality, improvement in plant capacity, deferral or elimination of capital investments, and reduction in environmental impact. All of these benefits go directly to the bottom line. The typical result has been a 20 to 40 percent reduction in overall unit manufacturing cost, a 10 to 30 percent increase in production rate, 5 to 15 percent increase in product selling price, and a 20 to 30 percent reduction in otherwise planned capital expenditures. Additionally, the environment realizes significant benefits, and the business can be made more secure and more profitable.

3.5 Automation of PEPR Procedures

It should be possible to automate the PEPR methodology and these procedures to a certain degree via software programming to introduce this methodology into other DOD industrial plants without having to sponsor a workshop at every location. A PEPR software tool can be designed to be tutorial in nature to teach the methodology—together with the PEPR workshop materials—and perhaps to inspire the energy and engineering personnel at DOD facilities to apply the PEPR methodology on their own. This concept of the potential usefulness of a PEPR software tool is a significant part of the rationale for the present project.

4 General Description of PEPR Screening Tool

4.1 Overview

The overall objective of developing the PEPR software is to automate PEPR-like procedures for initial project screening. Such a tool could aid in performing the equivalent of a PEPR analysis between Levels I and II. In addition, it would introduce the PEPR methodology to energy personnel at DOD facilities interested in applying it at their own location.

The PEPR tool has been developed initially to contain data encompassing five processes selected as being representative and significant in terms of energy and emissions. It can help:

1. Organize the available data
2. Bring data to the analysis from other sources and data bases
3. Ask appropriate questions to help a process analyst develop an improved process
4. Perform calculations of specific energy consumption, theoretical energy requirements, process energy efficiency, total energy consumption and cost, and pollutants generated.

The PEPR tool is being developed to include a data base of available data on the performance and the cost of possible process improvements for typical process unit operations in DOD industrial processes. It is envisioned that this tool will have the capability to develop rough, order-of-magnitude analyses of possible process improvements and energy and pollution reduction measures for screening and prioritizing them for further analysis.

The user's manual for this initial version of the PEPR software is included in this report as Appendix A.

4.2 Design Objectives

4.2.1 General

The PEPR software screening tool has been designed with these major objectives in mind:

1. Program flexibility and upgradability
2. Different types of program users
3. Process and data analyses to aid the user
4. Information for users on re-engineering processes.

These design objectives are discussed below in more detail.

4.2.2 Program Flexibility and Upgradability

First of all, the program is designed with maximum flexibility and upgradability. Its data bases have been designed to contain all the data necessary for complete and comprehensive process descriptions so that the widest variety of processes can be accommodated. The program is flexible in that it allows for a maximum degree of interactivity with a user who chooses to access any of the data bases. Data input screens are provided to ensure easy access to this data base. Data for additional processes are easily inserted into the data bases without additional modeling or programming.

The process expertise accumulated as the result of process studies can be incorporated into the program in several ways. Finally, the program can conceivably be upgraded with the addition of input data modules designed to lead a user through the data input procedure, if the program is used sufficiently to make this a cost-effective add-on.

4.2.3 Types of Program Users

The program is designed with two groups of users in mind: the user with some process-engineering expertise who will be interested in working directly with the process data, and the high-level user who will be interested mainly in the results of the process analyses and the comparisons of processes and ECOs. The data contained within the PEPR program are fundamental process data, and are input and manipulated at the most fundamental level of analysis, just as a process engineer would describe and analyze a process. The process-engineering type of user will be interested in using the functions of the program designed to help him analyze and develop improved processes.

However, the results of calculations on the process data contained in the data base are easily accessible to the high-level user. A user at a higher level who is interested only in comparing existing processes with process alternatives (i.e., ECOs) may access these results directly via a simple menu selection for this function. The desired process comparison is done simply by selecting the improved process (ECO) and the existing process as the baseline from the data base for a comparison, and by viewing the results.

4.2.4 Process and Data Analyses

The program is designed to aid both groups of users in performing process and data analyses with extensive analytical and calculational functions. For example, after the process-engineer type of user enters process data representing a new process into the program data base, they can be analyzed with a series of basic calculations. The program can calculate material and energy balances around each process unit operation so that the user may immediately see how good the data set is and make appropriate adjustments, if desired. (Some data sets may not be complete so that balances may not be appropriate, in which case this function may simply not be used.)

Both groups of users will be interested in the analysis of complete processes. Energy inputs and outputs, by energy type, are summed for the total process to give energy consumption per unit product. When multiplied by the annual production, the energy per unit product gives annual energy consumption for the entire process. Energy costs are also calculated with unit energy costs specific to the base selected from the Base Data Base. Emissions per unit product and annual emissions generation are also calculated. Data on hazardous air pollutants (HAPs) can also be included in the data base by process operation.

Finally, improved processes can be compared with existing processes with a series of calculations of the differences between them (the differences in energy consumption and energy costs) and an economic analysis of the life-cycle costs and savings.

4.2.5 Information on Re-Engineering Processes

The program is also designed to aid the user in re-engineering his process with several functions to access process expertise. For example, in addition to containing basic process data, the process data base is also designed to contain information regarding possible process improvements ("re-engineering suggestions"), which are associated with an existing process and have been collected as the result of prior expert analyses. The user can easily access this information in the data base. Second, there is an expert-advice routine for analyzing unit operation data, which can give suggestions for improving process operations. Finally, there is a data base of performance data and economic data on improved technologies that may be substituted into existing processes for analysis.

4.3 Program Concepts

4.3.1 Overall Organization of Data

As a general concept in the design of the PEPR program, it is important to understand that the data and the calculation routines are all oriented toward working with processes, and each process in the data base is attached (linked) to a specific military base. The reason for this organization of the data is that DOD industrial processes, even those in apparently the same general process category (heat treating, spray painting, electroplating, etc.), are base-specific: they may have different equipment, capacities, and energy requirements, and, in a process having numerous steps, possibly different unit operations.

In addition, there may be many variations of the same general process, even at the same base. The process variations must be accounted for in the data base because potential specific ECOs may be applicable only to specific variations of the same general process. In addition, because an ECO may be applicable only to a specific process, an improved process with an ECO (designated as such in the process data base) should be compared only with its baseline or existing process (also designated as such in the process data base).

4.3.2 Base Data Base

There is a data base in the PEPR software, called the Base Data Base, that contains general base information, name, location, and information on products and production lines, as well as other base-specific data such as energy costs. This data base in PEPR is based on the installation data base in the Renewables and Energy Efficiency Planning (REEP) program (Nemeth, Fournier, and Edgar July 1993), which contained a great deal of information usable by PEPR. The structure of the existing REEP data base was changed to accommodate some additional fields for the new types of data required by PEPR. The data fields contained in the REEP data base that appeared to be unnecessary for PEPR purposes were edited out.

Two new data fields of particular importance added to the Base Data Base in PEPR are factors for the percent loss of steam in the steam distribution system after the steam leaves the boiler, and a similar loss factor for compressed air. These factors can be significant in systems that are not well maintained. These factors are important in a PEPR analysis because a pound of steam, or a cubic foot of compressed air, saved at the process point-of-use becomes a much larger saving back at the central supply plant. This is true because the loss normally associated with supplying a pound of steam, or a cubic foot of compressed air, to the process is also saved. This saving of the energy loss is included in the calculation of the amount of energy saved through a process improvement and hence in the energy cost saved in the economic analysis.

Because a number of data bases in PEPR must work together, there are certain bits of "linking" data. The linking data are used by other data bases to access data in the Base Data Base are the base abbreviations, and have been defined for each base to be unique. The base abbreviations have been defined and loaded into the Base Data Base. Because these linking data are important, program operations have been defined to warn the user not to change them. In addition, when a base abbreviation must be put into the process data base, the user is cautioned to select the correct predefined abbreviation.

4.3.3 Process Data Bases

The data in the three process data bases are fundamental process data. Thus, each process is envisioned to consist of one or more separate steps or unit operations. Each process step or unit operation in turn is described by data on: (1) material inputs and outputs with process conditions of temperature and pressure, (2) energy inputs and outputs, by energy type, (3) emissions, by type, and (4) data on equipment specifications, especially motor size and efficiency.

For production processes that produce identifiable, quantified products (e.g., bombs, bullets, forgings, explosives, etc.), the data are assumed to be on the basis of per-unit-product. For generic operations or processes that may not have a readily identifiable or quantifiable product and a well-defined production line, but rather simply have material (and perhaps energy) inputs, the data may be put on the basis of per-unit-raw-material-used or even per-hour-of-operation. Examples of such generic operations are woodworking, printing, degreasing, (maintenance) welding, etc., to name a few. They consume materials and energy, and produce pollution, perhaps simply as a function of raw-material inputs or operating time, but are not part of a process that produces a specific product. With this foundation of basic process data, PEPR is designed to be as general as possible so that it can handle the widest variety of processes at the most fundamental level of analysis.

For a program user with an interest in doing fundamental analyses with process data, PEPR was designed to have a great deal of interactive capability. Consequently, the user can access a number of data bases directly, if wished, either for editing or for organizing the primary data on processes and emissions of interest. These data bases have been made accessible through the use of data input screens.

The PEPR program is designed to be as general as possible to be able to handle a wide variety of types of processes and data. To allow for this wide variety in processes requires allowing for a large number of different data variables, many of which may not be used for a particular process and will show up in the data base as blanks or zeroes. To handle the quantity and the different types of process data requires three separate data bases that are linked via several critical variables.

These three process data data bases are: (1) general process information, containing such information as process schedule, operating hours per year, bottlenecks, production capacity, etc., and ideas for re-engineering the process; (2) process operation data, with detailed data on each process operation comprising the total process, such as inputs and outputs of materials, energy, and pollutants, and process conditions; and (3) hazardous air pollutants (HAPs) data, by species and process operation.

The process data data bases contain two broad classes of processes, existing processes and improved processes. In terms of the data in the data base, improved processes are similar to existing processes, the only difference being the substitution of one or more improved technologies (ECOs) for one or more steps of an existing process. Since the data structures for both existing and improved processes are essentially the same, the data on all processes are placed in the same data bases, with a process-descriptor field ("Process ECO") for information to distinguish different process alternatives (Existing for existing processes and the name of an ECO for a correspondingly improved process). Because the analysis of improved processes (for less energy consumption, less pollution, better quality, etc., perhaps at an added cost) is done in comparison with an existing process on an incremental basis, each improved process is linked to a specific existing process.

4.3.4 Calculations

Each process in the data base may be analyzed by certain calculations material and energy balances, and theoretical energy requirements (provided that all of the required data are available for this calculation) for individual operations. This quantitative information can then be subjected to analysis by an expert-advice routine of expert suggestions that examine the operation data and pose questions intended to stimulate the user's thinking regarding potential process improvements. This routine also generates comments and quantitative estimates, where appropriate, for savings in energy consumption and/or emissions based on a quick analysis and rules of thumb regarding potential process improvements. It is anticipated that this routine will be updated and expanded as the result of being used and reviewed by experts.

In addition, a significant number of calculations are included in the program for analyzing a complete process, such as total energy consumption, energy costs, total emissions, etc. (see Section 4.5 below). Because of the large number of calculated results allowed for, to store all of the results would require another very large data base. To keep the data bases as simple as possible, therefore, most calculations are done "on the fly" and are stored in temporary storage for immediate viewing and printing, etc. If some results are needed somewhere else for another purpose, such as a comparison between processes, the calculations are simply repeated.

4.3.5 Improved Processes

The user has complete flexibility to input data into the program to describe his concept of an improved process for comparison with an existing process in the process data base. However, the PEPR program has a function to assist the user at the process engineering level to develop improved processes. This function works by generating an improved process by substituting one or more improved operations into the baseline existing process. The improved operations are determined on the basis of user-selected improved technologies taken from a data base of new technologies for specific operation types. Each substituted process step is generated by a data base/routine specific for a selected improved technology to develop rough figures for improved energy consumption and pollution generation scaled to the input of one of the input materials.

The improved-technology data base used for selecting improved technologies is organized on the basis of certain types of information on each improved technology, such as general operation type (e.g., drying, conveying, spray painting, etc.), specific improved technology (e.g., infra-red drying, microwave drying, water-based latex paint, powder paint, etc.), and the process/product that was the source and the basis for the improved technology. The data base also contains data for each improved technology used by the specific routine for each improved technology for process and cost calculations. The organization of the improved-technology data base and the type of information contained in it thus resemble the data base (of ECOs) in the REEP program.

The function of the routine for each improved technology in the data base is to generate new process data for the improved operation; this procedure may involve interactions with the user in the form of questions for pertinent information. As one example of such an interaction, the question may be asked about which material flow the capacity and the cost of the equipment should be based on. The improved-operation data are then generated by the routine from the improved-technology data (by adjusting material, energy, and emissions flows, and capital cost for capacity, for example) and put into the data base for the improved process. The new improved process can then be analyzed and compared with its baseline existing process, including an economic analysis of the improved process as it relates to the existing process.

4.4 Software Environment

The PEPR program was developed using Microsoft FoxPro Version 2.6 for Windows. FoxPro is a Relational Data Base Management System (RDBMS) with a built-in programming language that allows for the development of custom applications requiring the manipulation of, and calculations on, data organized into a data base. PEPR is a compiled executable program and therefore does not need FoxPro itself to run. PEPR was developed to run on an IBM PC or compatible with an 80386 or higher microprocessor, and requires approximately 8 megabytes of disk space. The PEPR system was developed for a Windows environment and requires Microsoft Windows 3.1 or higher to run properly.

With respect to the programming environment of PEPR, several approaches could have been taken. For example, it could have been programmed from scratch in C or Pascal, or some other such basic computer language, rather than in a data base environment. However, it was thought that there would be some advantages in having the program look like, and have the feel of, similar programs developed for USACERL, such as the Central Heating Plant Economics (CHPECON) program (Lin et al. January 1995) or the REEP program. These programs, as well as the Naval Air Emissions Tracking System (NAETS) program (J. I. Northrup et al. January 1995), were developed using FoxPro data base software. Since it may be desired in the future to link these data bases with PEPR, it was thought that PEPR should also be programmed in FoxPro. PEPR was, however, programmed in FoxPro Version 2.6, which has some differences as well as some improvements over Version 2.5, on which REEP is based.

However, FoxPro has a number of limitations, particularly for an intensively interactive program such as PEPR. There are more advanced, simpler-to-program data base languages available now, such as Microsoft Access. In Access, for instance, reports are simpler to create. FoxPro and Access are both Microsoft data base languages now, and it would be possible to convert PEPR, as a FoxPro program, into an Access program in the future with perhaps a relatively modest amount of effort. Even if PEPR is never converted to Access, future additions to PEPR, such as new reports, could be readily programmed in Access and added to the initial FoxPro version of PEPR.

4.5 Results

4.5.1 *Process Analyses*

The initial result from the program is the analysis of each process that has been defined in the process data base. This analysis is done for both existing "as-is" processes and new alternative processes, and consists of a number of basic calculations. For each process, the total energy requirements by energy form (steam Btus; compressed air; motor electrical power; nonmotor electrical power; cold water; hot air; hot water; etc.), and total emissions by type (air, water, and solid emissions) are calculated from the requirements for the individual process steps. For each process step, the theoretical energy requirement (if this calculation is appropriate; otherwise a zero will appear), and a theoretical energy efficiency are calculated. Comparing the actual versus the theoretical energy efficiency highlights those process steps having the most potential for process energy reduction. Similarly, an analysis of the process emissions highlights those process operations with the most potential for emissions reduction.

After the analysis of the existing process, the program can then help the user define and analyze process alternatives incorporating one or more ECOs, using either available data included in the process data base on the performance and the cost of alternative processes, or data in the improved-technology data base on new technologies for substitution for individual process steps or unit operations. The user can then analyze each process alternative with an ECO by calculating the total energy requirements and the new total (reduced) emissions, and comparing the results with those for the existing process. Life-cycle costs are calculated for each process alternative.

4.5.2 *Outputs*

The program has several types of outputs. First, the program outputs the results of the existing "as-is" process analysis—the total energy requirements and total emissions (broken down by energy and emission type). Similar output is available for each process alternative with an ECO analyzed. Then each process alternative can be compared with the existing "as-is" process. The output from a comparison of two processes consists of: (1) a comparison of energy requirements and emissions—the reductions in energy requirements and emissions, in terms of both the specific quantity (per unit product) and the total quantity per year, and (2) the results of an economic analysis of the process alternative compared with the existing process as the baseline.

It may also be of interest in the future to add enhancements to the program to aggregate the results from comparing the alternatives for a particular process across all of the DOD facilities analyzed. (To develop a credible result for this calculation, however, the process data base must contain sufficient data on the specific processes at individual bases, which data generally lack at present.) In this case, the output could consist of a total reduction in energy or emissions, at a total cost, achieved by implementing specified ECOs and process alternatives to a specific process at a number of DOD facilities.

4.5.3 Use of the Program

The program data base has been developed initially to analyze five selected processes. However, it is anticipated that this program will be used on other processes in the future. The future success of this software tool in analyzing DOD industrial processes, and identifying, analyzing, and selecting alternative processes for energy and pollution reduction will depend on the quality and the quantity of site-specific data inserted into the program, and the amount of specific information included in the data base on alternative processes incorporating ECOs.

Thus, as the program is used to analyze additional processes, the collected data on existing processes and the results of studies on alternative processes should be used to update the software and its data bases. The software has been made flexible and easy to update, and it should be updated periodically with the results of various users' studies. The file for each DOD facility should be updated periodically, and the software should be used on a regular basis for each facility to use the new information in the updated data bases.

5 Opportunities for Process Energy and Pollution Reduction

5.1 Overview

One of the most important objectives for the work on this project was to develop a list of ECOs for the five processes studied. In addition, appropriate alternate technologies were to be identified. To accomplish this objective requires that a sufficiently detailed process description with equipment descriptions, and energy usage and emissions data be available for the baseline process. As noted earlier, however, previous energy studies on DOD industrial processes generally lack sufficient detail by themselves on: (1) descriptions of the process equipment and its present condition, (2) operational parameters, (3) process conditions, and (4) the amount of energy consumed and pollution generated to provide a firm basis for proposing specific energy-reduction measures. Therefore, it was necessary to supplement this information from outside sources (e.g., equipment vendors, etc.) and use engineering judgment to make up deficiencies.

This chapter describes the five processes studied during the course of this project, including opportunities for energy reduction. The information on these processes was obtained for the most part from previously published studies, or from relatively quick and informal inquiries. Since many of the reports available were completed a number of years ago, there is the question of whether such a description and the data are still current. With more detailed, up-to-date information, other possible ECOs with potential could be defined.

The five processes described below include: (1) a load, assemble, and pack line, (2) an explosives production process, (3) spray painting, (4) electroplating, and (5) heat treating. Each of the following sections discusses:

1. General introduction to the process
2. Specific example
3. Discussion of energy and emissions data and issues
4. List, discussion, and evaluation of ECOs
5. Discussion and list of re-engineering suggestions.

This chapter is supplemented by Appendix B, which contains the details of the estimation and the evaluation of each ECO.

5.2 Load, Assemble, and Pack Lines

5.2.1 Introduction

One very common general type of process carried out at many Army industrial bases is to "load, assemble, and pack" (LAP) various types of munitions. The same general process is used, with some variation in individual unit operations or steps, for ammunition, various types of shells, and missiles. In the typical LAP line, there are only a few significant process operations involving either energy or emissions, and some of these operations may be slightly different, rearranged, or perhaps omitted for different types of munitions. Briefly, the most significant process unit operations are:

1. Processing of the explosive—melting the trinitrotoluene (TNT) or perhaps blending powders with the aid of a solvent that is eventually evaporated
2. Preheating the empty shell (sometimes omitted)
3. Probing the filled shell on a probe machine to eliminate cavities in the melted explosive and adding more explosive if necessary (sometimes omitted)
4. Painting and stenciling as sources of emissions (not all can yet be controlled)
5. Post-cyclic heating of the assembled projectile, which is generally the most conspicuous consumer of energy by far in the entire process.

Two of the more complete energy studies of any DOD industrial process from the process point of view that were available for this initial PEPR project were two "process energy inventory" studies conducted at the Iowa Army Ammunition Plant (IWAAP) in 1981 and 1983. With this information, it was possible to put together a fairly complete process description with energy consumption data for a typical production line (Line 3 at IWAAP) at a LAP plant, although some significant gaps remain in the data. The analysis of this process should be broadly typical of a number of similar lines and processes at other LAP-type plants. To illustrate a typical LAP process, the description of the process and the data on energy consumption for Load Line 3 for "LAPing" M106 shells taken from these references are shown below.

5.2.2 Example—LAP Process for M106 Shells

The M106 is an 8-in. projectile weighing approximately 200 lb and containing approximately 36 lb of TNT. A process flow diagram for its production is shown in Figure 1.

The metal parts are received at the loading line storage building and are transferred to the receiving and painting building when needed. There they are depalletized, inspected, placed on transfer carts, and moved to the melt loading building. TNT is received at the TNT service magazine and transferred to the TNT screening building as needed. It is inspected and screened, and then transferred to the melt loading building.

Projectiles are preheated in an oven maintained at 125 °F. TNT is melted on a 5-psig (228 °F) steam-heated melt grid. TNT is transferred to a Dopp kettle where it is mixed with unmelted TNT to the proper consistency for pouring (188 °F). Approximately 36 lb of TNT are poured into each projectile, and the filled projectiles are allowed to cool for a minimum of 2 hours.

The filled projectiles are probed with a hot probe (220 °F) to a depth of 15 in. to remove the cavitation formed in the casting during cooling. Melted TNT is then poured into the hole left from probing, and the projectiles are again allowed to cool. Following this cooling, a second hot probe to a depth of 5 in. is performed, followed by a second add-pour operation.

When cooled, the projectiles are drilled, and a liner is inserted for the supplementary charge. The projectiles are x-rayed to check for defects. Accepted shells are transferred to the final assembly building. Defective shells are transferred to the melt building where they are pumped out and recycled back into the process flow at the preheat-oven stage. The accepted shells are touch-up painted, weighed, and stenciled. The supplementary charge is inserted, and the lifting plug is assembled. The shells are then transferred to the post-cyclic heating area where they are maintained at 135 °F for 12 to 18 hours, allowed to cool to not less than 70 °F for 12 hours and reheated to 135-150 °F for 12 to 18 hours. The shells are then shipped out or stored in appropriate locations.

5.2.3 Energy and Emissions Data and Issues

Figure 1 shows energy consumption and emissions data. A summary of these process operations was developed as a representation of the process to put into the PEPR program. In developing this summary from the reported information, some

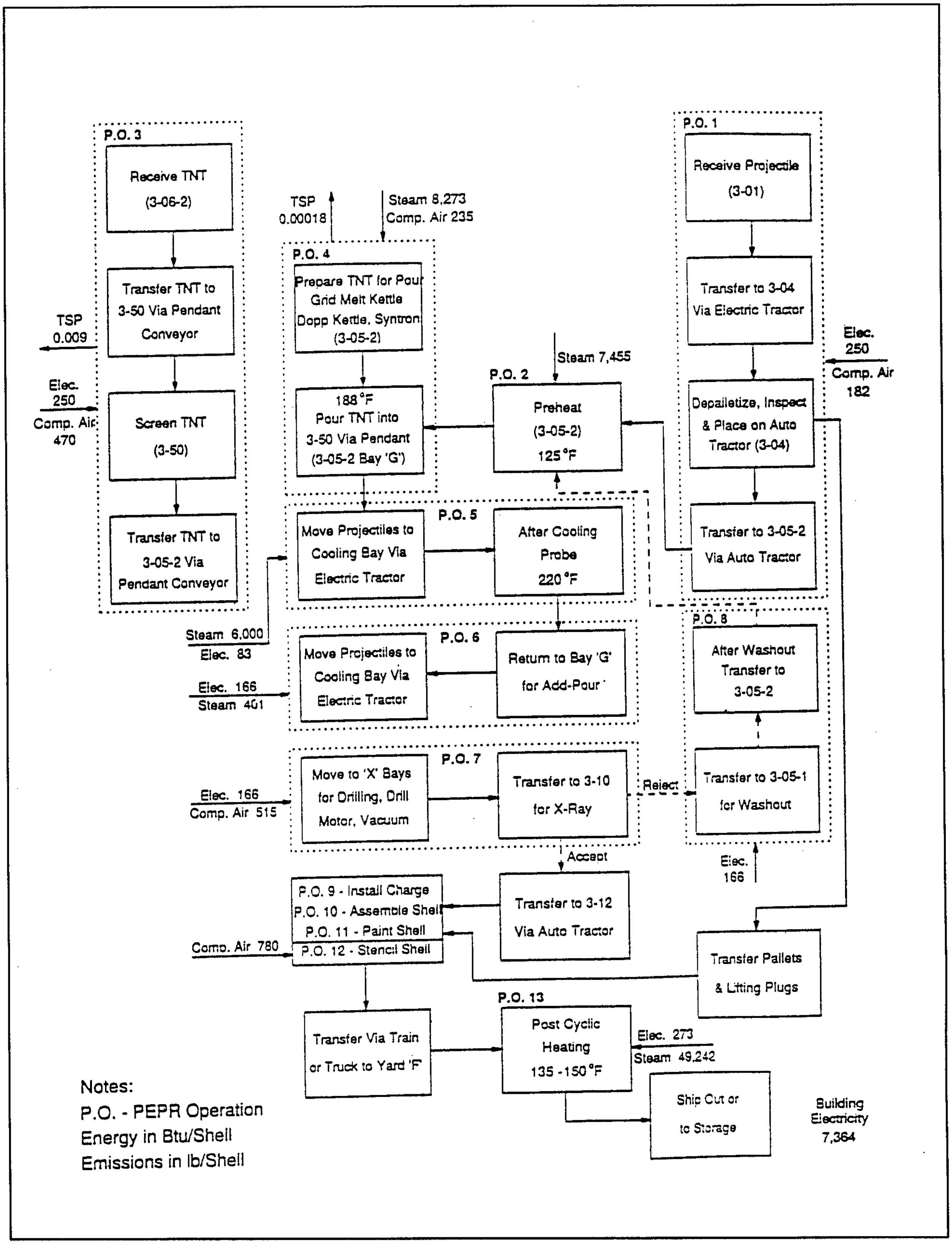


Figure 1. Process block flow diagram for producing M106 shells.

process steps, which neither consume a great deal of energy nor produce emissions, were lumped together.

For the purposes of PEPR analyses, there is not much point in carrying process steps like these along as individual operations; in early stages of the analysis, it is best not to get lost in such detail. Steps consolidated to simplify a daily analysis, can always be broken out later when more data might become available on, for example, conveyor energy consumption or expected number of rejects involving reprocessing with additional energy demands.

For producing M650 8-in. shells, which also weigh about 200 lb, the process steps and energy requirements are very similar to those described in Figure 1. For producing M17A1 warheads, which contain 650 lb of an explosive mixture consisting of RDX, TNT, aluminum, and wax, the process steps are also very similar to those in Figure 1. However, in this latter case there is no shell preheat, and the melt-pour step theoretically consumes 10 times as much energy.

5.2.4 Energy Conservation Opportunities (ECOs)

In the typical LAP line described above, only a few significant steps involve either energy or emissions, and these steps have been described above. Other characteristics of these processes stand out on the energy supply side. In the energy analysis done at IWAAP, the total annual steam consumption for Line 3 was found to equal the sum of theoretical energy requirements, standby losses, and piping losses. Standby losses are those losses incurred by leaving the steam turned on to the equipment during off-shift hours. Piping losses are those incurred by not insulating the process equipment properly. These results indicate that inefficiencies of the steam supply—piping and standby losses, etc.—and standby losses of the ovens must account for a significant part of the inefficiency in using energy. The point of this analysis is that energy savings in the steam supply at the point of use (as opposed to the point of steam generation) may be the most significant energy savings to be achieved in relatively low-energy-intensive LAP processes.

As the result of the prior analysis at IWAAP (in 1981) and the identification of the major inefficiencies in energy usage, two ECOs were identified and savings were estimated for their application to the process discussed here. The ECOs identified were automatic controls and insulation of the process equipment. These ECOs are described in more detail below.

Some ECOs identified and analyzed were found to be impractical: (1) recirculate melt tower air, (2) use air compressor waste heat, and (3) reclaim heat from high-pressure steam traps. Other ECOs were identified, but not analyzed: (1) install motor controllers for electric and air motors, (2) install power-factor controllers for electric motors, (3) isolate bays not in use, and (4) insulate cooling bays and recirculate heat.

The ECOs identified for LAP processes are listed in Table 7. The quantitative data for those ECOs for which this information is available and put into PEPR are also shown, as are the results of the analysis by the PEPR software. Details of the quantified ECO analyses are contained in Appendix B.1.

5.2.4.1 Automatically Turn Process Heat Off and On. To ensure that the heat producing equipment is at the proper temperature at the beginning of a shift, steam must be left on during off-shift hours. Substantial energy could be saved by using a timer-controller to heat the equipment to the proper temperature by the beginning of a shift. For the annual production of M106 shells, the savings in steam could be an estimated 1,540 MBtu/yr of steam (11,700 Btu per M106 shell produced). This saving in steam was estimated as the sum of the amount of steam consumed by each of a number of pieces of equipment (preheat oven, grid melt unit, Dopp kettle, steam probe, and hot-water probe) during nonuse hours over the course of 50 weeks for the year (multiplied by a factor of 85 percent, assuming that this portion of the steam could be saved).

5.2.4.2 Insulate Heat-Producing Equipment and Piping. A significant amount of energy could be saved by devising a suitable method for insulating certain process equipment and piping. A large quantity of equipment such as melt kettles, melt grid units, volumetric loaders, etc., as well as steam-jacketed explosives piping, steam piping, and hot-water piping is currently not insulated. An analysis was made by IWAAP to estimate the heat energy that could be saved by insulating this equipment. Insulating the process piping with 3 in. of insulation was estimated to save 394 MBtu/yr in steam (2,985 Btu per M106 shell produced) at an estimated cost of $20,300, insulating the heating system piping 438 MBtu/yr (3,318 Btu per M106 shell produced) at a cost of $37,000, and insulating the process equipment 167 MBtu/yr (1,265 Btu per M106 shell produced) at a cost of $4,900.

5.2.4.3 Substitute Natural Gas for Steam in Post-Cyclic Heating Operation. Piping steam from the central steam supply to provide steam to the ovens used for post-cyclic heating appears to be inefficient. Converting the ovens to use natural gas for heating would make these heating operations cheaper and more efficient.

Table 7. List of ECOs and re-engineering suggestions for LAP process at IWAAP.

Description of ECO	Capital Cost ($)	O&M Saving ($/yr)	Energy Saving MBtu/yr	Payback yr	Return on Investment, %	Savings-to-Investment Ratio (SIR)	Remarks
ECOs in PEPR Software							
Automatically turn process heat on and off.	12,500	na	1,540 3,310[2]	1.8	16.6	9.83	
Insulate process piping.	20,300	na	394 847[2]	11.2	6.3	1.55	
Insulate heating piping.	37,000	na	438 941[2]	18.3	3.7	0.94	
Insulate process equipment.	4,900	na	167 359[2]	6.4	9.3	2.72	
Substitute natural gas for steam in post-cyclic heating operation.	13,000	na	-1,147 6,320[2]	1.4	16.7	10.05	
Non-quantified ECOs							
Analyze post-cyclic heating operation and ovens for heat losses and increased efficiency, e.g., capture waste heat from cooldown cycle for preheat.							
Re-engineering Suggestions							
Re-design the initial pour step to eliminate cavities, and thus the probe and add-pour steps, for more efficient operation.							
Optimize or eliminate post-cyclic heating operation.							

[1] Energy saved at the process.
[2] Energy saved in primary fuel, considering losses in central steam and compressed-air supply systems, and efficiency of steam generation.

5.2.5 Re-Engineering Suggestions

In the PEPR methodology, energy conservation measures do not go far enough. An important prior question is whether it continues to make sense to try to rehabilitate and operate a large centralized steam supply system at these Army facilities. LAP production lines apparently do not require high-temperature steam.

Perhaps the Line 3 building and production line can be adequately supplied by its own small package boiler supplying relatively low-pressure steam or even only hot water. Smaller decentralized steam supply systems would appear better suited for the low-capacity, sporadic production schedules of the future for these Army facilities, particularly if the energy required for heating these production buildings can be more economically supplied with gas-fired infra-red radiant unit heaters in place of inefficient and inefficiently supplied central steam heat.

With respect to emissions, the biggest problem seems to be the painting and stenciling steps. The other production steps appear to have pollution control equipment (dust collectors, etc.), but the spray paint booths have only dry filters or water curtains to control total suspended particulates (TSP). There appear to be no controls for volatile organic compounds (VOCs). Rather than implement VOC control on every spray paint booth in the Army, the most cost-effective measure to control VOCs resulting from painting would appear to be to switch to water-based paints with considerably fewer VOCs to emit to the atmosphere upon drying or curing.

With respect to making the post-cyclic heating step more energy-efficient, it would be worthwhile to analyze these ovens in detail. Their major inefficiencies may be the inefficiencies involved in supplying steam to them and keeping them on standby; they apparently are not located in Building 3 with the production line, but are outside in another area. Perhaps they should be renovated to use steam from their own source rather than from a central supply, or some other source of heat, such as natural gas, or propane if a gas line is not available. Perhaps the waste heat from each cooldown cycle can be recovered to preheat an incoming batch. Gauging this potential for energy conservation in these ovens would require more information on the specific units involved. Another approach would be to eliminate the operation of post-cyclic heating altogether if possible (see below).

This brief description of the LAP process as found in the literature does not provide sufficient information about the equipment used in the process, operational procedures, or reasons for some of the procedures to support firm recommendations regarding possible ways to "re-engineer" the process. However, it is possible to raise some questions and suggestions. For example, the probe and add-pour operations would appear to be production bottlenecks. Can these operations be made more efficient? Why do cavities form when the melted TNT cools, making the probe and add-pour steps necessary? Is air entrained in the melted TNT when it is poured into the shell, or are the cavities formed by off-gases from the TNT?

Knowing how and why the cavities form would support the development of ideas for possibly eliminating or simplifying the probe and add-pour operations. The melted TNT could possibly be poured more slowly into the shell to allow partial cooling to take place and occluded vapors to be released during pouring. Perhaps the pouring could be done with the shells held on an angle to help keep cavities from forming.

The time-temperature relationship for the post-cyclic heating step should be optimized, with the specific objective of this heating operation kept firmly in mind. The purpose of this operation is frequently to simply test munitions for leaks after several thermal cycles. Since this operation is a major energy consumer, some research should perhaps be done to develop an alternative method of testing shells for leaks, or to develop a process modification to positively seal the shells and eliminate the need for this thermal testing procedure for quality control.

5.3 Explosives Production

5.3.1 Introduction

One of the more energy-intensive types of industrial processes carried out in Army industrial facilities is the manufacture of explosives. Some of these processes for explosives production are typical chemical processes with chemical reactions involving significant thermal effects and integrated heat exchange among process streams, although others—for example, the production of nitroglycerine—do not have significant energy consumption or thermal effects. The production of primary explosives, which are then shipped to other Army facilities for use as basic materials in assembling various munitions, tends to be concentrated in only two facilities: (1) Radford Army Ammunition Plant, which produces trinitrotoluene (TNT), nitroglycerine, and nitrocellulose (NC), and (2) Holston Army Ammunition Plant, which produces research development explosive (RDX) and high melting explosive (HMX).

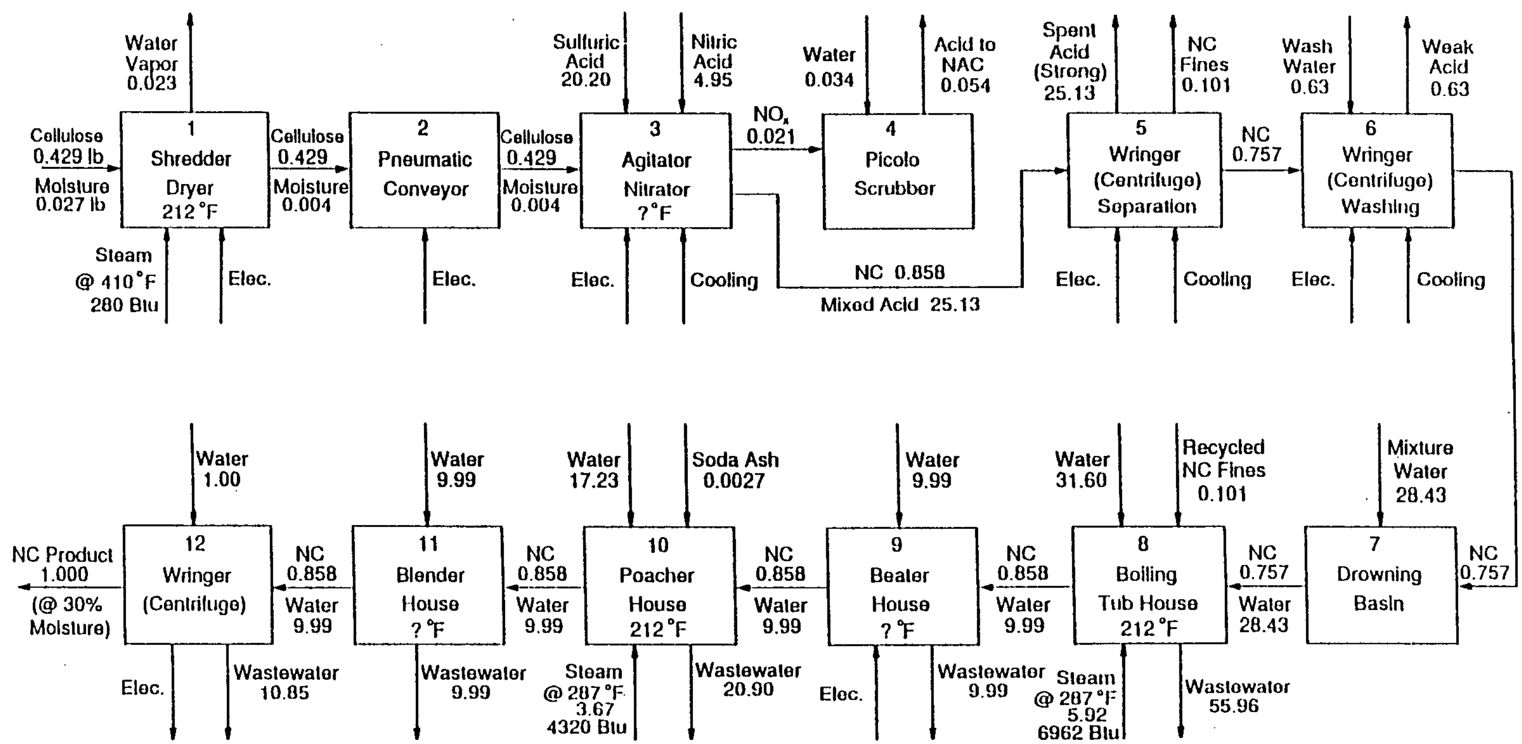
Although each of these explosives is produced with its own unique process, there are certain elements common to all of the processes; each process typically involves a nitration reaction with mixed acids followed by various purification steps to stabilize the nitrated product, neutralize it, and perhaps wash it. The processes for RDX and HMX are quite similar, since both are simply variants of the Bachmann process. Each process does require somewhat different supporting processes to produce and prepare the feed materials, with some commonality in, for example, nitric acid production, nitric acid/sulfuric acid concentration (NAC/SAC), and sulfuric acid recovery. As a production process to put into the initial PEPR data base, NC production at Radford was selected. Previous studies of various types have been done on this process so that some energy consumption data and descriptions of process operations were available in published reports.

5.3.2 Example—Nitrocellulose Production

NC is a basic ingredient produced and used at Radford in the manufacture of smokeless powder, small arms propellants, and rocket propellants. It is produced by treating purified cellulose with a mixture of nitric and sulfuric acids in Hercules proprietary reactors in a multi-step process, which is illustrated in the block flow diagram in Figure 2. After an initial drying operation and the basic nitration chemical reaction, the process involves neutralization of excess acid and several washing operations with the consumption of large amounts of hot water.

5.3.2.1 Drying of Cotton Linters and Wood Pulp. NC production begins with the preparation of either cotton linters or wood pulp. In the dryer room, bales of cotton linters are unwrapped, broken up, fluffed, and fed into the dryer. At the end of the dryer, the dried material is dropped onto a conveyor and conveyed to the nitrating house hopper room. The moisture level of the cotton is reduced from about 6 to 1 percent in the drying process. The moisture level of wood pulp is reduced from about 5 to 0.5 percent. The dryer is heated with 260-psi steam (410 °F), and the conveyor consumes a relatively small amount of electricity.

5.3.2.2 Nitrating House. In the nitrating house, the cellulose fibers are contacted with a solution of mixed sulfuric and nitric acids. The fibers are nitrated by the nitric acid, resulting in a mixture of NC and water. Water is absorbed by the sulfuric acid, which not only reduces the water content in the NC, but also serves to maintain the strength of the nitric acid. The nitration procedure is carried out in a nitrator reactor, which consists of a series of eight vessels, with acid and cellulose flowing in a multi-stage countercurrent operation. The nitration reaction is exothermic (it gives off heat). From the last reactor, the NC/acid mixture is sent as a slurry to a centrifuge. The mixture of NC and acid is separated in this step. From the centrifuge, the acid-wet NC is put into a drowning basin to be submerged by a heavy stream of water. The resultant NC/water slurry is then pumped to the NC purification area. Generally, the material is transferred in a slurry with 5 percent solids (by weight). The spent acid from the centrifuge is sent to screen tanks where the NC fines are removed by a baffle and settling tank. Acid separated by the centrifuge is of two different concentrations. The stronger acid is sent to storage to be reconstituted for reuse in the nitration reaction. The weaker acid is sent to the NAC/SAC unit to be concentrated. An ammonia brine system cools the centrifuge.



Quantities of materials in lbs
Average production rate = 14,000 lb NC/hr

Figure 2. Process flow block diagram of nitrocellulose production.

The nitrator reactor and the centrifuge consume electricity, but no data are available on how much.

5.3.2.3 Fume Scrubber and Molecular Sieve. Fumes from the nitration area are captured and sent through a picolo fume scrubber and molecular sieve to reduce NO_x emissions; the weak acid produced is sent to NAC/SAC.

5.3.2.4 Boiling Tub House. After nitration, the crude NC undergoes a series of purification and stabilization treatments to remove impurities. The boiling tub house treatment is the first of these treatments, where the NC undergoes a long acid-boil treatment. From nitration, the NC slurry is pumped to large tanks in the boiling tub house. The water in the tub is boiled after its acidity is adjusted for the particular NC being manufactured. After the acid boil, the NC is washed with fresh water and given a neutral boil. This neutral boil is repeated twice before the treatment is finished. The wash water is heated with 40-psi steam. The tanks have false bottoms so that the acidic wastewater, which contains some NC fines, can be drained and sent to the settling pits.

5.3.2.5 Beater House. After the boiling tub house, the NC slurry is pumped into similar tanks in the beater house. This building contains Jordan beaters, which house concentric blades to cut the NC fibers. These beaters cut the fibers to a specified length to ensure that the acid is washed out in subsequent operations. The beater process consists of six Jordan beaters set up in series. After the NC slurry is sent through the beater process, it is screened to filter out excess water. The slurry of specification fibers is stored in a tank until it is pumped to the poacher house. The water in the tanks not needed to transport the slurry is decanted off and sent to the settling pits.

5.3.2.6 Poacher House. After the NC is cut, it is pumped to the poacher house for further purification. The pulped fibers still retain acid on their surfaces. This acid is removed by poaching the NC; the poaching process neutralizes the acid released by the pulping operation and gives the NC a thorough wash. The NC slurry is pumped to large tanks, and soda ash is added for neutralization. It is then alternately boiled and agitated or washed and drained for a specified period of time. After an NC "lot" has been accepted by the laboratory, it is screened to remove coarse, insufficiently cut fibers. The NC is dewatered by a rotary vacuum filter. Filtered and recovered water is stored in a tank and reused in this process when available.

5.3.2.7 Blender House. In the blender house process, poacher batches of NC are blended to the required specification for the propellants being manufactured. Appropriate solubility and nitrogen content of the NC is obtained by blending "lots" of higher and lower grades of NC in a blender unit. After the blending operation, the NC designated for the manufacture of smokeless powder and rocket propellant is sent to the final wring house. For other products, the NC may be used as a slurry. Any excess water is decanted off and sent with the washdown water to the settling pits.

5.3.2.8 Final Wring House. When the product is thoroughly blended, the slurry is pumped to the final wringer or centrifuge where the water is removed. The NC slurry is dewatered to its specified moisture content of about 30 percent. The final product is loaded out of the bottom of the centrifuge into bags and weighed. The water drained from the NC is sent to the settling pits along with all the equipment and building washdown water.

5.3.2.9 Poacher and Blender Settling Pits. The water drained off from the beater, poacher, blender, and final wring houses is sent to the poacher and blender settling pits where fine NC is settled out of the water. The water that leaves the settling pits either drains into the general-purpose sewer, or is pumped into a reservoir for reuse in the NC area. The NC that has settled out is reused.

5.3.3 Energy and Emissions Data and Issues

Energy consumption data are shown in Figure 2.

There appear to be some opportunities for re-engineering the most significant energy-consuming operations of the NC production process, in keeping with the PEPR methodology. The operations that should be the focus of such an effort are: (1) the dryer used to dry the feed material, (2) the various washing operations that consume large amounts of hot water, and (3) the cooling required for the nitrator and the centrifuge.

5.3.3.1 Dryer Options. One might question whether the dryer is necessary. The amount of moisture taken out of the feed material is relatively small, only 5 to 6 percent of the weight of the material. This amount of moisture may or may not be an important variable affecting the quality of the final product, in view of the possibly more important natural variation of the quality of the feed material. Since the cotton or wood pulp used as feed material is a natural material, its composition and quality are variable. Hence, quality control is necessary, being conducted on the final product in the form of analyzing for nitrogen content and blending product from different lots to produce a batch that meets desired specifications.

The nitration reaction is conducted with a large excess of sulfuric acid to take up the water produced by the reaction, which is about equal to 33 percent of the weight of the dry feed material. The amount of moisture that might be left in undried feed material would be a small amount of additional water to be taken up by the acid—about 15 percent more water. The amount of sulfuric acid added to the reactor might have to be increased to compensate. This small amount of additional water in the reactor would probably not impact the reaction very much. This additional moisture taken up by the acid would have to come out of the system somewhere, of course (in the operation to concentrate the acid), but it would be a more efficient way to remove this moisture. Not having to operate the dryer would save a significant amount of high-pressure steam (no data are available on how much), and would also eliminate a source of particulate emissions (dust in the heated air from the dryer).

If, after some experimentation and research, the dryer is found to be necessary, certain options are available to make its operation more efficient: (1) investigate the possible use of lower-pressure steam in the dryer, (2) try to find a need for thermal energy that could be satisfied by heat exchange with the hot exhaust from the dryer (e.g., filter the hot exhaust air to remove particulates and then blow it into one of the batches of wash water that need to be heated—heat recovery via direct heat exchange), (3) convert the dryer to use natural gas for heat instead of steam, and (4) investigate the use of advanced drying methods, such as microwave or infra-red drying.

5.3.3.2 Boiling and Poacher Tubs. In addition to the use of insulation and heat recovery systems on the boiling tubs, other energy conservation options might be explored. For example, the warm-up period of possibly several hours required with indirect heat exchange to heat the water in the filled tub to the desired temperature could be eliminated by using a direct steam injection system to heat the hot water to the desired temperature instantaneously as it enters the tub. Direct heat exchange would be more efficient, the heat losses from the tub during warm-up would be eliminated, and productivity of the tubs (average throughput per unit time) would also improve with a decrease in overall batch time.

Energy consumption in the boiling and poacher tubs is consumed in the form of large amounts of hot water in multiple one-use washes. Energy and water both could be conserved if a batch of hot water could be drained from one lot of NC, filtered or settled to remove the NC fines from that lot, and then reused to wash the next lot. The general idea is to reuse hot wash water with adequate filtration between batches to control potential contamination between different lots of NC, to simulate a countercurrent washing process with the dirtiest or most used water being used as the first wash of the incoming lot of NC, which might have the most material to be washed out of it.

After washing this incoming batch of NC, the dirtiest water might then be dumped to the water treatment plant if it cannot be recycled further. Apparently, some water is presently reused in the poacher house, but the concept of water reuse could perhaps be applied in the boiling tub house through proper sequencing of washing operations and developing an appropriate method for filtering or making the hot water between washes reusable.

5.3.3.3 Nitration Reactor and Centrifuge. Data are not available on how much cooling is required for the nitration reactor and the associated centrifuge, and for the temperature requirements. The use of cold brine for cooling, however, requires the use of electricity for refrigerating the brine. It would be cheaper to find a way to use cooling water for this purpose, perhaps by using incoming fresh water on its way to one of the washing operations.

5.3.4 Energy Conservation Opportunities (ECOs)

The NC process at Radford has been studied relatively recently for potential energy conservation opportunities. Two opportunities identified specifically for the NC production process were (in addition to installing more efficient motors) to: (1) insulate the boiling and poacher tubs, and (2) modify the boiling tub heating method by using heat recovery to preheat incoming water via heat exchange with drained hot water from a previous batch. The ECOs identified for the NC production process are listed in Table 8. Table 4 also lists quantitative data for those ECOs for which this information is available, or for those ECOs that have been estimated and put into PEPR. Also shown are the results of the analysis by the PEPR software. Some ECOs described below cannot be quantified because the information on process equipment and operations necessary for their analysis was not available during this study.

5.3.4.1 Use More Efficient Drying Technology. More efficient drying technologies than (very inefficient) convection drying have been developed, such as microwave and infra-red dryers. One of these newer drying technologies should be considered. An infra-red dryer could be fired with natural gas, which would be cheaper and more efficient than using steam from the central steam supply. Since each technology has its own advantages, disadvantages, and optimum applications, appropriate research and testing would have to be done to make sure that one of these technologies is suitable for drying these kinds of materials.

5.3.4.2 Convert Dryer To Use Natural Gas Instead of Steam. Convection dryers can be heated with any one of a variety of energy sources. High-pressure steam is used at Radford because it probably was the cheapest form of energy when the plant was designed and was producing at capacity. However, using natural gas would be

Table 8. List of ECOs and re-engineering suggestions for nitrocellulose production at RAAP.

Description of ECO	Capital Cost ($)	O&M Saving $/yr	Energy Saving MBtu/yr	Payback yr	Return on Investment, %	Savings-to-Investment Ratio (SIR)	Remarks
ECOs in PEPR Software							
Use more efficient infra-red drying technology.	110,000	na	4,748 14,331[2]	-5.3	[1] ---	-1.84	Substituting more expensive energy saves coal
Convert dryer to use natural gas instead of steam.	13,000	na	-1,400 8,182[2]	-0.7	[1] ---	-39.62	Substituting more expensive energy saves coal
Insulate boiling and poacher tubs.	75,064	na	5,056 11,237[2]	4.0	12.1	4.45	
Recover heat via heat exchanger in tubs to preheat incoming water.	130,700	na	93,492 207,760[2]	0.4	[1] 26.1	47.2	
Non-quantified ECOs							
Use hot dryer exhaust to heat batch of wash water.							
Use direct steam injection to heat batches of wash water.							
Reuse batches of wash water via countercurrent washing process.							
Re-engineering Suggestions							
Eliminate dryer.							
Find cheaper source of cooling for nitration reactor and centrifuge (e.g., use fresh wash water).							

[1] Energy saved at the process.
[2] Energy saved in primary fuel, considering losses in central steam and compressed-air supply systems, and efficiency of steam generation.

cheaper and more efficient than using steam—especially high-pressure steam—from the central steam supply.

5.3.4.3 Use Hot Dryer Exhaust To Heat Batch of Wash Water. Because a typical drying operation is very inefficient, there is a great deal of low-temperature thermal energy contained in the hot exhaust air from the dryer. This energy should be recovered in the most cost-effective way. One conceivable way in which this might be accomplished would be to duct this stream of hot moist air into a batch of incoming cold wash water to preheat it. The air should probably be filtered first because it will contain dust and particulate matter. Indirect heat exchange with a heat exchanger could be used if it is preferred to avoid direct contact between the exhaust air and the fresh water to be used for washing the NC in one of the washing operations.

The contiguousness of the drying building and either the boiling tub or the poacher house would be an important consideration regarding the feasibility of this scheme. It would not be feasible to duct the hot air any great distance.

5.3.4.4 Insulate Boiling and Poacher Tubs. The boiling and poacher tubs appear to be uninsulated at present, resulting in a significant loss of thermal energy during the extended periods of washing at boiling temperature. Insulating these tanks is a difficult proposition because they must be washed down periodically to prevent the accumulation of NC fines. A system for insulating the tanks that maintains the washability of the process equipment was recently designed and estimated to decrease these heat losses.

5.3.4.5 Recover Heat via Heat Exchanger To Preheat Incoming Water. When another batch of fresh water is pumped into a tub to begin a wash cycle, it can be pumped through a heat exchanger located in a tub filled with hot water, which is at the end of its wash cycle. This allows the fresh water to be preheated, thus saving on the amount of steam needed to heat this next batch to boiling.

5.3.4.6 Use Direct Steam Injection To Heat Batches of Wash Water. It is not clear from the available information how steam is used to heat the water in the large tubs used to wash the NC in various operations. Using indirect heat exchange to heat the large volume of water in a wash tub to boiling requires a significant time for heating. Injecting the steam directly into the water after the tub has been filled also requires a significant amount of time. This preheat period apparently can take anywhere from 2 to 8 hours (average of 4 hours). Instead, the incoming wash water could be heated essentially instantaneously to boiling by using a direct steam injection system. Besides saving time from each wash cycle, this method would also save energy by being more efficient.

5.3.4.7 Reuse Batches of Wash Water via Countercurrent Washing Process. With the current system of washing, each batch of hot water is dumped after it is used once, with a consequent loss of the thermal energy. It is then usually sent to settling pits so that NC fines can settle out. Currently, the water is sometimes reused, depending on the particular process area, instead of simply being dumped into the sewer; this water reuse appears to be done mainly to save water. However, energy could be saved as well by expanding this water reuse into a system of countercurrent washing in which:

1. Fresh wash water (perhaps preheated by cooling the nitrator or the centrifuge, or by heat exchange with the batch of wash water about to be dumped) would be heated instantaneously via steam injection and used as the final wash or boil for a particular NC lot
2. This batch of wash water would then be filtered or settled, and used as the next-to-last wash or boil for another NC lot
3. The process would continue down the line of tanks until the last time the batch is used (and finally settled and dumped) for the first wash or boil of an incoming dirty NC lot.

For each time that the batch is reused, a bit of extra steam may be needed to maintain the boiling temperature, but the essential result should be the multiple reuse of the thermal energy used to heat the batch to boiling in the first place.

This proposed method of reusing hot wash water carries the heat recovery scheme suggested above for using heat exchangers in the tubs to recover heat one step further, to reuse and thus save water and thermal energy.

5.3.5 Re-Engineering Suggestions

A number of specific ideas have been discussed above for improving the operation of the NC production process, in addition to ECOs. These re-engineering suggestions, which cannot be easily quantified at this time, are:

1. Eliminate the dryer used to dry the feed material, or make it more efficient by: (a) using lower-pressure steam in place of the high-pressure steam (if lower-pressure steam is available), (b) finding a use for the thermal energy in the hot exhaust air (see ECOs for one example), and (c) using a more efficient drying technology (see ECOs for example).
2. Figure out how to reuse the wash water in the boiling tub and poacher houses to the maximum possible extent.
3. Find a cheaper source of cooling for the nitration reactor and centrifuge than using refrigerated brine (for example, use incoming fresh wash water).

5.4 Spray Painting

5.4.1 Introduction

Spray painting is a very common unit operation at Army industrial facilities. Virtually every Army facility has one or more spray paint booths, either as a standalone operation used sporadically a few hours each month in equipment maintenance or product touch-up, or continuously as an integral part of a production process. The painting in a spray paint booth may be done manually with a spray can, brush, roller, or spray gun, or automatically via spray nozzles. Various types of paints are used in these spray paint booths with significant potential particulate, VOC, and HAP emissions. The degree of control of these potential emissions is usually dictated by local regulations. At the present time, particulate emissions are usually controlled, while VOCs may not be.

Spray paint booths come in a variety of configurations. Some are completely enclosed or are open on only one side, while others simply have two walls to confine the painting operation to a portion of the building volume. Spray paint booths may be designed as walk-in floor models, bench-type models, or conveyor-type booths. The selection, design, and operation of a spray paint booth are affected by the materials sprayed, method of spraying, production rates, plant layout, product size, and code requirements. Spray booths and components are designed to meet NFPA, OSHA, NEC, and EPA regulations, as well as local code requirements.

Spray paint booths are generally designed to control the potential pollution that may result from the overspray of paint materials not captured by the object being painted. At the present time, the major concern with pollution control is to control particulate matter. The control of VOCs can be accomplished only with the use of optional additional equipment. Paint particles escaping in the exhaust air from the spray booth are generally controlled in one of two ways: (1) a water wash, or (2) a dry filter. There are several different configurations of each major type.

The following discussion places major emphasis on the energy requirements and potential for improvements in energy consumption, pollution reduction, and reduction in operating costs for the operation of spray paint booths, using a large vehicle drive-through booth at Rock Island Arsenal as an example.

5.4.2 Example—Vehicle Drive-Through Booth

Figure 3 shows a schematic diagram of a large drive-through two-sided system installed at Rock Island Arsenal (RIA).

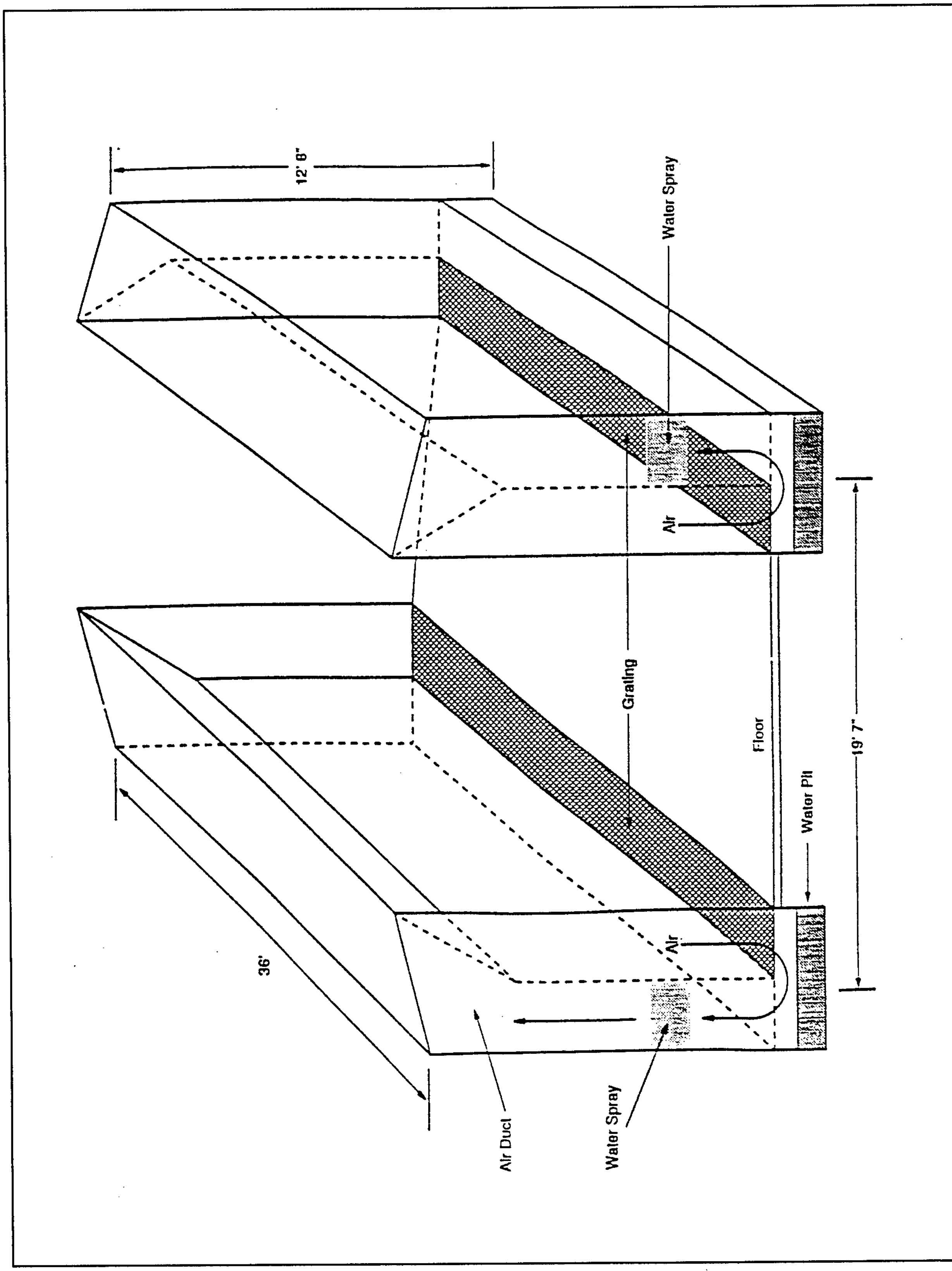


Figure 3. Large drive-through, two-sided spray booth at RIA.

The operation of the paint booth is fairly straightforward. The air circulation (and the water circulation too, if the booth contains a water bath or curtain) is turned on. The vehicle is placed in the booth, and one or two painters using spray guns attached to paint sources with flexible hoses spray paint on the object, until sufficient paint has been put on the object to meet specifications.

The paint booth may be seen as a construction of several subsystems:

1. An air circulation subsystem
2. A spray paint gun subsystem
3. A water circulation subsystem
4. The type of paint being sprayed.

The type of paint is included in this list because its characteristics influence the performance of the paint booth, both in terms of energy consumption and, especially, emissions. These different aspects of paint booth operation are discussed in more detail in the subsections below.

5.4.2.1 Air Circulation. One of the most important considerations in the design of a spray paint booth is the amount of air to be circulated through it during operation. The purpose of this air is to rapidly and thoroughly remove volatile paint and solvent fumes to prevent their accumulation and concentration to hazardous levels. The air moving through the booth also carries paint overspray away from the product, thus mitigating the finish-marring consequences of semi-dry paint particles settling on already-painted surfaces. With a well-engineered mass air flow, a spray paint booth tangibly promotes product quality.

5.4.2.2 Paint Spray Systems. Presently, there are four major processes of spray applications:

1. Compressed air atomization (conventional air spray and high-volume, low-pressure spray [HVLP])
2. Airless atomization
3. Air-assisted airless atomization
4. Electrostatic atomization, which can be combined with any of the previous three processes.

Each process has its advantages and limitations. A complete discussion of all of these spray techniques is beyond the scope of this study. However, because HVLP is a relatively new technique now being introduced into some DOD facilities, it may be useful to compare this process with the older conventional spray process.

Conventional air spray is the oldest system; it remains today as the finishing system most widely used in industry. Conventional air spray has two main advantages: (1) it is the most controllable process available, and (2) it is the most versatile and the easiest system to operate and maintain. One disadvantage is a low level of transfer efficiency (around 35 to 40 percent); more material is wasted than is actually deposited on the part. It also consumes large amounts of compressed air, in the range of 7 to 35 cfm. Depending on the spray equipment, type of paint, and desired pattern, it requires air pressures in the range of 30 to 100 psi.

HVLP atomization works in a similar manner to conventional air spray except that the air jets exiting the nozzle are columns of high-volume, low-pressure air. The spray guns are specially constructed for this service. The benefits of HVLP atomization are: improved transfer efficiency (which may approach 75 percent), compliance with local finishing regulations, a softer spray that penetrates easily into recesses or cavities, reduced material consumption, which consequently reduces spray booth maintenance and hazardous waste. The most notable limitation is that the finish quality is not as fine as that obtained from conventional air spray. This may mean additional polishing, a change in the material formulation, or switching to electrostatics. Turbine-generated HVLP systems may be expensive to purchase and operate. High-volume production lines may find HVLP to be too slow. HVLP systems use between 15 to 30 cfm and 1 to 10 psi air pressure, depending on the type of paint and its density and viscosity.

The example paint booth at RIA uses conventional spray guns (Binks Model 2001 with special tips).

5.4.2.3 Water Circulation Subsystem. In a spray paint booth, particulate emissions are frequently controlled by contacting the air being circulated with a water bath or a water curtain to scrub the emissions from the air. The scrubbing water is circulated by a pump. In another configuration, a dry filter can be used for particulate control instead of the water scrubber.

The example paint booth at RIA has a water curtain to control particulate emissions, although it will probably be converted to use a dry filter.

5.4.3 Energy and Emissions Data and Issues

5.4.3.1 Energy Usage. In a typical paint booth, energy is consumed in several ways. Electricity is used to drive fans that circulate the air through the paint booth. This air picks up paint particles and other emissions. If the booth has a water circulation system, the circulation pump consumes electricity. The compressor air used to operate the spray painting equipment also consumes electricity, although the amount of energy consumed in spraying the paint is generally considered to be relatively small.

Thermal energy is consumed in the wintertime to heat the air circulated through the paint booth. Since this air is circulated on a once-through basis, heating this air can require a great deal of energy; this is the most significant energy usage in the system.

Table 9 shows the amounts of energy consumed in these various ways by a spray paint booth at Rock Island Arsenal.

5.4.3.2 Drying. Another possible use for energy in the spray painting operation is to dry the paint in a heated space, such as an oven. The energy used may be either thermal energy or electricity. However, whether such forced drying is used or whether the painted part is simply left to dry under ambient conditions depends on the type of paint and, perhaps, the desired rate of production. The example paint booth at RIA does not have a forced drying step; the painted object is left to dry under ambient conditions.

5.4.3.3 Emissions. The amounts of VOC and HAP emissions depend on the type of paint or other coating used in a paint booth. The amount of particulate emissions depends on the solids content of the particular paint and the amount of overspray, which is a function of the type of spraying equipment used. For conventional (low-volume, high-pressure) spray guns, a transfer efficiency of 40 percent is frequently assumed (therefore 60 percent of the paint and its solids comprise the overspray and particulate emissions [TSP], to be controlled by either a dry filter or a waterfall).

Table 9. Energy usage in spray paint booth (Building 208) at Rock Island Arsenal.

System	Parameters	Motor Size (hp)	Btu/hr of operation
Air circulation	4 exhaust fans 120,000 cfm of air heat	4 x 25 hp	299,400* 3,452,000**
Wash water circulation		40	119,800*
Spraying equipment	1 gun, requiring on average 21 cfm @ 65 psig (conventional)		6,870***

* Assuming 85% motor efficiency.

** Estimating the amount of heat necessary to heat 1) the once-through air during booth operation and 2) the amount of air infiltration during non-operating hours during the heating season, averaged over the operating hours during the year.

*** Assuming that 1 gun is used during the hour of production and producing the required compressed air requires 2.3 hp of electric power @ 85% efficiency.

PM_{10} emissions are 100 percent of TSP for a dry filter and 50 percent of TSP for a waterfall booth. VOC and volatile HAP emissions (usually not controlled) are assumed to equal the amount of each in the quantity of paint used. Table 10 shows the amounts of these various types of emissions estimated to be generated from the spray paint booth at RIA from spraying polyurethane paint.

5.4.4 Energy Conservation Opportunities (ECOs)

The largest amount of energy usage in a typical spray paint booth, without forced drying, is to heat once-through makeup air for circulation through the booth. The minimum amount of air that must be circulated through a paint booth is governed by regulations. Typically, this required amount of air circulation is calculated as the booth width times its height times a required air velocity of 100 to 125 fpm. In some newer booth designs, a certain portion of the air circulated through the booth may be recirculated, thus decreasing the net amount of makeup air required and the thermal energy used to heat it. This type of booth is suitable, however, only for powder coatings (i.e., coatings without VOCs).

In any case, for energy conservation, the amount of air circulated through a paint booth should be reviewed to see if it is excessive and can be reduced, perhaps by controlling the speed of the exhaust fans—above the required minimum amount to meet applicable regulations. Applicable regulations should be reviewed to see if the amount of air circulated can be reduced if low-volatile-content paints are used.

Table 10. Pollution generation in spray paint booth (Building 208) at Rock Island Arsenal.

Property and Emission Type	Paint Composition (polyurethane)	Emissions lb/gallon of paint		Emissions lb/hr of operation (@ 2 gal/hr)	
		Uncontrolled	Controlled	Uncontrolled	Controlled
Density	11.68 lb/gal				
Solids	35.0%				
TSP		2.45	0.049*	4.90	0.098
PM_{10}		1.23	0.025*	2.45	0.050
VOCs	62.0%	7.24	7.24	14.48	14.48
HAPs					
Xylene	5%	0.58	0.58	1.17	1.17
Methyl ethyl ketone	10%	1.17	1.17	2.34	2.34
Chromium compounds	10%	0.70	0.014*	1.40	0.028
Toluene	5%	0.58	0.58	1.17	1.17

* Assuming 98% control of particulates and 50% of particulate emissions is PM_{10}.

The idea of conserving energy by transferring heat from the warm exhaust air to the fresh incoming air has been studied. However, the main problem with this concept is that the heat-exchange surfaces in contact with the exhaust air tend to become fouled with paint particles. There is also the potential problem of leaks in the exchanger, leading to contamination of the incoming air with paint from the exhaust air. Although this concept is not presently implemented, it should perhaps be considered for possible development.

With respect to emissions control and improved pollution prevention, water-wash paint booths can be converted to dry systems in which the paint-particulate-laden air flow is directed towards a packed-media filter. Eliminating the wet scrubbing of the air eliminates wastewater to be treated and the cost of the chemicals added to the water bath to coagulate the paint particles, as well as the power consumed to operate the water pump. Dry filters can perhaps be disposed of as nonhazardous waste, depending on the kind of paint, whereas wet paint sludge is considered hazardous. For one specific paint booth RIA estimated significant annual savings in O&M costs ($22,451) as the result of converting a water-wash booth to a dry-filter system (capital cost $1,670). For disposal of the paint-laden filter material, RIA sells this material to an outside source, which apparently burns it for its Btu value.

However, water-wash systems are regarded as the most efficient for removal of paint particles from exhaust air regardless of paint viscosity or drying speed. Their use is especially indicated where production is continuous. Particulate control efficiency for a large booth using a water wash can be as high as 97 or 98 percent. For a dry-filter system, which is most suitable for smaller booths using slow drying or light-viscosity materials, with perhaps intermittent or light production, control efficiency may be only 90 to 95 percent. Required fan power for circulating the air through the booth is slightly higher for a water-wash system than for a dry filter.

Table 11 lists the ECOs identified for spray paint booths. The table also gives quantitative data for those ECOs for which this information was available and for those ECOs already put into PEPR. The results of the analysis by the PEPR software are also included.

5.4.4.1 Decrease the Amount of Air Circulation. The specifications for air circulation of an operating booth are generally subject to regulations regarding minimum air flow. However, since the booth was originally designed, the air circulation system may not have been maintained, and the amount of air being circulated may be more than is required. The fans may be oversized and may circulate more air than necessary. In addition, if low-volatile-content paints are being used, less VOCs are being emitted that have to be ventilated from the booth. Thus, the amount of air

Table 11. List of ECOs and re-engineering suggestions for spray paint booth at RIA.

Description of ECO	Capital Cost ($)	O&M Saving $/yr	Energy Saving MBtu/yr	Payback yr	Return on Investment, %	Savings-to-Investment Ratio (SIR)
ECOs in PEPR Software						
Decrease the amount of air circulation.	0	na	624 1,387[2]	—	—	—
Consider the use of HVLP spray guns.	285	22,000	12 16[2]	0.01	48.1	1172
Consider converting a water-wash booth to a dry filter.	1,670	22,451	240	0.06	76.2	195
Consider installing a CentriClean System in large water-wash paint booth.	32,985	23,105	-15	1.4	16.8	10.2
Install automatic dampers to close the exhaust ducts.	6,700	na	598 1,329[2]	2.6	14.2	6.5
Non-Quantified ECOs						
Examine the air requirements for the paint spray system being used to see if the pressure of the air supply system can be reduced.						
Investigate the concept of developing a suitable heat-exchange system for exchanging heat from the warm exhaust air to the cold incoming makeup air.						
Re-Engineering Suggestions						
Investigate the efficiency of the system for heating the makeup air, and try to find a source of waste heat for doing this.						
Develop a robotic system for the specific types of objects to be painted to standardize the process and the amount of paint used.						
Investigate the use of newer alternative paints and coatings.						

[1] Energy saved at the process.
[2] Energy saved in primary fuel, considering losses in central steam and compressed-air supply systems, and efficiency of steam generation.

being circulated should be measured and controlled to the minimum. Perhaps the amount of air being circulated can be reduced.

5.4.4.2 Consider the Use of HVLP Spray Guns . An HVLP spray gun is a more efficient painting system that uses considerably less paint, produces less paint waste, and emits fewer VOCs to the atmosphere than conventional airspray systems. Investigate the use of HVLP guns for specific types of paints and specific spray paint booths.

5.4.4.3 Consider Converting a Water-Wash Booth to a Dry Filter. Cleaning the paint sludge out of the washwater pit in a water-wash paint booth can be expensive and lead to the generation of hazardous waste. Investigate the cost-effectiveness of converting the booth to a dry-filter system.

5.4.4.4 Consider Installing a CentriClean System in Large Water-Wash Paint Booth. In the conventional design of a booth using a water-wash system, the water is recirculated. Chemicals suitable for the specific material being sprayed are added to the water bath to treat the water and to coagulate the paint particles. The cost of the chemicals, of cleaning out and disposing of the coagulated paint sludge, of system downtime for cleaning, and of treating wastewater can all add up to a considerable cost to operate a water-wash-type of spray paint booth.

Although RIA found that converting one water-wash-type of booth to a dry-filter system was very economical, such conversion may not always be cost-effective, particularly for large booths. As an alternative to the conventional way of operating a water-wash booth, there is a simple and innovative sludge dewatering system now available for automatically dewatering, compacting, and discharging paint solids from water-wash spray booths. This system, called the CentriClean (Binks Manufacturing Company) Sludge Dewatering System (other companies have comparable systems), is reported to have the following advantages:

- recycles booth water
- reduces disposal costs
- uses no filters or other consumables
- minimizes paint waste volume
- requires low maintenance
- has low utility requirements.

Four different models are available, depending on the desired rate of water through put in gpm, costing from $6,545 to $44,265. The two larger units are used for operations that usually spray more than 30 gal of paint a day. Table 12 lists the characteristics of these CentriClean units.

5.4.4.5 Install Automatic Dampers To Close the Exhaust Ducts. Whenever the air circulation system in the booth is turned off, a draft through the open ducts loses heat. Install automatic dampers in the exhaust ducts to close off the ducts whenever the exhaust fans are not running.

5.4.5 Re-Engineering Suggestions

Due to increased regulatory requirements of the Clean Air Act, many advances in the painting industry have been designed to increase the efficiency of painting applications. Such improvements include improvements in paint spray systems to reduce overspray and alternatives to control emissions. Some newer designs of spray paint booths are being developed to conserve energy as well.

5.4.5.1 Efficiency of Painting Process. One way to increase the overall efficiency of spray paint booths, with significant impacts on energy usage and emissions control as well, is to increase the efficiency of the painting process. Reduced Overspray Paint Technology has been developed to replace standard gun systems, which typically have a transfer efficiency of only 35 percent. High-volume, low-pressure (HVLP) systems have a transfer efficiency of about 75 percent. Increasing the transfer efficiency of the spray painting system can greatly reduce waste and air contamination.

Table 12. Characteristics of Binks CentriClean units.

Type	Model No.	Water Flow Rate, max. gpm	Sludge Generation gal sludge/shift	Required Power hp	Capital Cost $
Manual	C-50M (29-200)	10	1-3	2.0	6,545
Manual	C-80M (29-201)	15	3-6	3.0	8,315
Automatic	C-100A (29-202)	18	6-22	3.0	32,985
Automatic	C-150A (29-203)	30	>22	5.0	44,265

Source: Private communications between Benjamin Mallen, Binks Manufacturing Company, and Malcolm Fraser, Science Applications International Corporation (May 1995).

Table 13 lists the energy efficiencies of conventional and HVLP spray guns on the basis of average estimated requirements. It is difficult to make a precise comparison because the energy consumption of paint spray guns is impacted by many variables and has not been considered significant enough to measure.

As the result of the greatly increased transfer efficiency of HVLP spray guns, and resulting reduced waste of paint, the use of HVLP guns should result in a greatly reduced usage of paint to get the same coverage. However, the painters need to be trained in the proper use of HVLP guns to effect these savings. Another way to obtain savings in the amount of paint used is to use robotic systems for painting.

5.4.5.2 Different Types of Coatings. The operation of spray paint booths can be improved significantly with the introduction of new and different types of paints or coatings, that may have fewer emissions or better quality, or that may lead to greater productivity. The type of paint used in a spray paint booth might have a significant positive or negative effect on energy usage, and may significantly impact on emissions. For example, the use of powder coatings, waterborne paints, or radiation-cured coatings could reduce VOC emissions significantly, but lead to greater energy usage by requiring the use of ovens for baking, drying, or curing. The use of a newer paint or coating in an existing spray paint booth would have to be researched to determine if the booth could handle such a coating. In addition, research and development would be required to investigate the use of newer coatings for military applications and to change product specifications affected by the use of such coatings.

5.4.5.3 Other. Improved control of VOC emissions can be implemented with the addition of activated carbon beds and/or ultraviolet light systems. •

Table 13. Energy efficiencies of paint spray guns.

Type of Gun	Required Air Flow (cfm)	Required Air Pressure (psig)	Power to Operate hp (Btu/hr)	Energy Consumption to Deposit Same Amount of Paint[2,3] (Btu)
Conventional (LVHP)	7-35	30-100	0.5-4.7 (1,500-14,000[1])	1,500-14,000
HVLP	15-30	1-10	0.06-1.0 (180-3,000[1])	100-1,600

[1] Required power is assumed to be supplied at 85% efficiency.
[2] For HVLP 75% of paint sprayed is deposited versus only 40% for conventional guns.
[3] To achieve indicated potential savings, the pressure of the compressed-air supply would have to be reduced.

5.4.5.4 Summary of Improvement Options. The specific ideas discussed above for improving the operation of spray paint booths via re-engineering are:

1. Review the specifications and regulations for air circulation for an operating booth to see if the amount of air being circulated can be reduced.
2. Examine the air requirements for the paint spray system in use to see if the pressure of the air supply system can be reduced.
3. Investigate the use of more efficient paint spray systems such as HVLP for specific types of paints and specific spray paint booths.
4. For a smaller water-wash booth used in intermittent production, investigate the cost-effectiveness of converting the booth to a dry-filter system.
5. For a larger water-wash booth used for continuous production, investigate the cost-effectiveness of the CentriClean (or equivalent) system for sludge collection and dewatering for reducing the cost involved in handling waste paint sludge.
6. Investigate the concept of developing a suitable heat-exchange system for exchanging heat from the warm exhaust air to the cold incoming makeup air.
7. Investigate the efficiency of the system for heating the makeup air, and try to find a source of waste heat for doing this.
8. Develop a robotic system for the specific types of objects to be painted to standardize the process and the amount of paint used.
9. Investigate the use of newer alternative paints and coatings.

5.5 Electroplating Processes and Shops

5.5.1 Introduction

A wide variety of electroplating processes are employed at DOD installations. These processes are used to apply coatings to metal parts for corrosion protection, passivation, lubrication, wear protection, and material buildup. One of the most commonly used processes is hard chrome plating on steel. In the next section, the individual steps or operations involved in the hard chrome electroplating process are identified, described, and evaluated. Some quantitative process data are provided.

However, process energy usage in an electroplating shop is difficult to relate to a specific process line. A plating process is a series of batch operations, and data are not available on the times involved for the different operations. Energy data, if available at all, are more typically collected for the shop as a whole. In addition, production is frequently not measured in a way that can be related easily to energy consumption and emissions per unit of production. The best unit of production would be "plated area," but data of this type are usually not available. In another section below, data for an entire electroplating shop are presented and discussed. This representation of the energy consumption involved in plating processes, where similar operations with similar amounts of energy consumption are lumped together, is the one implemented in PEPR. Possible measures to reduce energy consumption and pollution generation are then discussed.

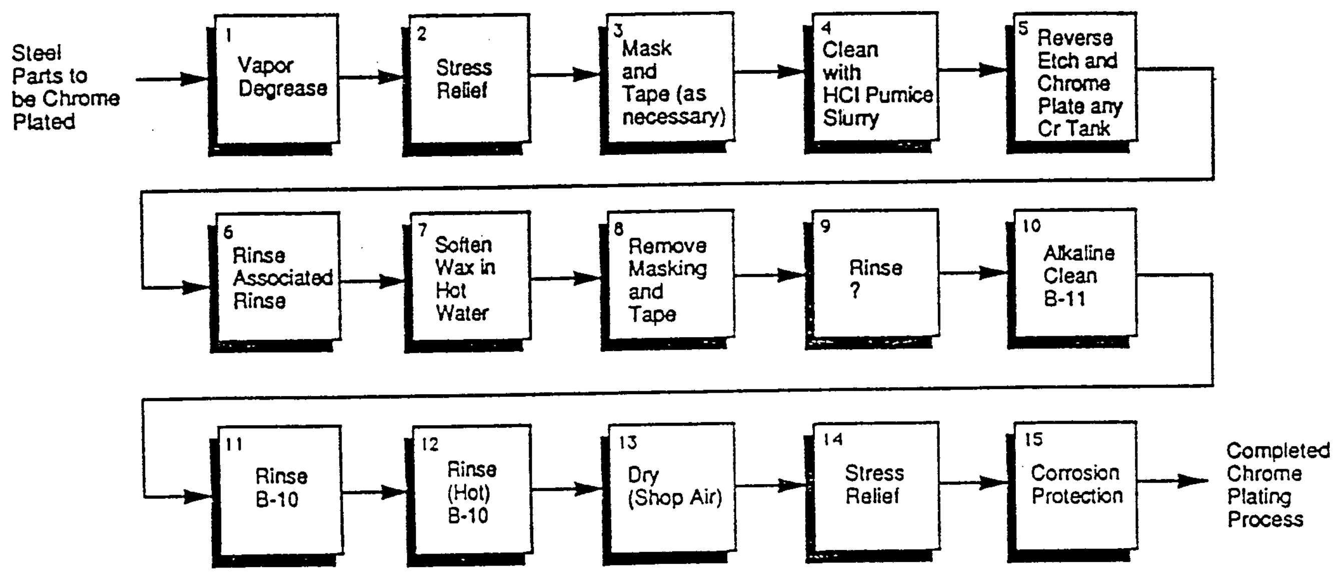
5.5.2 Examples—Hard Chrome Plating Process and Plating Shop

5.5.2.1 Hard Chrome Plating Process. Hard chromium plating involves depositing a coating of chromium onto a metal part. The chromium coating is produced by immersing the metal part in a chromic acid (CrO_3) solution, which may contain one or more catalytic anions, and applying a DC current through the solution. The hard chrome deposit confers a combination of physical and mechanical properties to the coated surface, such as high hardness, abrasion resistance, low coefficient of friction, good corrosion resistance, high heat resistance (up to 400 °C), and nonstick and anti-seizing properties. The hard chrome process is used to rebuild or salvage worn parts.

The usual thickness range of hard chrome plating is 2.5 to 300 µm. In general, a final deposit thickness of 125 µm after postplating grinding is considered adequate for the majority of applications. For wear resistance and anti-seizing properties, a thickness range of 12 to 50 µm is satisfactory. Frequently, parts are overplated up to 100 percent to allow for an adequate thickness for uniform grinding. However, this amount of overplating would appear to waste energy and materials; overplating should be controlled at a lower level for conservation.

The process consists of a number of procedures carried out in sequence such as degreasing, masking, cleaning, plating, rinsing, and others. These steps can vary depending on the specific requirements of the work. Figure 4 shows a typical layout of the hard chrome plating process as applied at the Corpus Christi Army Depot (CCAD) plating shop. The procedure for plating ferrous metals heat treated to a tensile strength less than 220,000 psi includes the following steps:

1. Degrease the parts (vapor degreasing or, in the future, power washing)
2. Alkaline clean the parts
3. Stress relieve the parts as required by the drawing or engineering specification
4. Shot peen when required by applicable technical documents
5. Mechanical finish (prepare preplate surface finish)
6. Rack and mask as required
7. Alkaline clean and scour as needed
8. Rinse thoroughly in cold water (room temperature)



Source: Day and Zimmerman, *Plating Shop Upgrade and Modernization Program Corpus Christi Army Depot* (February 1991).

Figure 4. Hard chromium plating process diagram.

9. Etch
10. Chromium plate
11. Rinse in cold or hot water and blow air onto the part to facilitate drying
12. Remove masking material and dry all surfaces
13. Bake ferrous alloy parts as soon as possible after plating (within 6 hours).

The plating procedure for steels heat treated to 220,000 psi and over (the process presented in Figure 4) consists basically of the same steps, excluding alkaline cleaning, and including cathodic treatment in sulfuric acid before plating. A brief description of the major procedures with typical parameters and material consumptions is provided below. Since the major goal of this assessment is to recommend measures for reduction in energy consumption and pollution, the analysis here is focused on the chemical and the thermal processes, rather than the processes for mechanical surface treatment.

***5.5.2.1.1* Vapor Degreasers**. Vapor degreasing is the process of cleaning metal parts by condensing pure solvent vapors on them, thereby flushing off the oil, grease, or soil. The cleaning action continues until the temperature of the part reaches the temperature of the vapor, at which point the condensation ceases. The part can then be removed from the degreaser, clean and dry.

A basic vapor degreasing unit is an open-top tank with a heat source at the bottom to boil the solvent and a cool surface around the upper section to condense the vapors. The solvent vapors form a vapor zone above the boiling solvent, extending up to the cool area provided by condensing coils and a water jacket.

Pure vapors are generated by heating the liquid solvent in the boiling sump of the degreaser. The heating source can be steam, gas, electricity, or hot water. The solvent vapors rise, displacing the air in the tank. They are confined by condensing coils and a water jacket below the freeboard area located in the upper section of the degreaser. Solvent vapors reaching this cool zone are condensed on the cooling coils, to be collected, routed through a water separator, and returned to the boiling sump.

The solvent used in vapor degreasers is typically one of four chlorinated solvents: 1,1,1-trichloroethane, trichloroethylene, perchloroethylene, or methylene chloride. The most important property of the solvent is the boiling point. If the boiling point is high, as it is for trichloroethylene and perchloroethylene, then a high-temperature heat source, such as high-pressure steam, is needed to vaporize the solvent. On the other hand, if the boiling point is low, such as the value for methylene chloride, then refrigeration is needed for the condensing coil, rather than simply using cooling water. Trichloroethane is frequently used as a good compromise between these constraints.

However, chlorinated solvents are being phased out for environmental concerns, as regulated by the USEPA under the 1990 Clean Air Act Amendments. As a result, vapor degreasers will come under extremely tight regulation. Consequently, most vapor degreasers are being phased out, to be replaced in plating shops by power washers.

***5.5.2.1.2* Power Washing**. Power washers clean and degrease using a recirculating hot biodegradable detergent and water solution instead of a solvent. The dirty parts are loaded into a basket that is inserted into the washer and set onto a turntable. As the turntable turns, solution is sprayed through jet nozzles at high pressure onto the parts in the basket from every angle. After the parts have been washed, they can be dried by means of high-velocity air jets. The washers are generally equipped with automatic skimmers to skim the oil and grease from the solution for disposal. The solution is heated to around 200 °F using steam, electricity, or gas. Gas is preferred, of course, from the viewpoint of energy efficiency and cost. Electricity is used to power the solution circulation pumps.

***5.5.2.1.3* Alkaline Cleaning**. Alkaline cleaning is used to remove oils, smuts, and light scale. This type of treatment is usually performed with highly alkaline salts, such as sodium hydrochloride, silicates, and carbonates, along with sequestering agents, dispersants, and various surface-active agents. Cleaning is usually done at elevated temperatures (120 to 200 °F) at salt concentrations ranging from ½ to 2 lb/gal. Application is by spraying, soaking, and/or electrocleaning. With "soak cleaning," soil is removed almost entirely by the surface action of the alkaline cleaner, since there is very little agitation of the solution.

Although it is not clear what method is used at the CCAD facility for cleaning metal before the hard chrome plating process, it appears that spray cleaning is used for ferrous metals. A tank assigned for alkaline cleaning at CCAD has a capacity of 202 gal, in which the cleaner MIL-14460 with a concentration of 24 oz/gal and a temperature of 190 °F is used with the minimum dwell time of 15 minutes.

***5.5.2.1.4* Stress Relief**. High-carbon-steel parts that have been subjected to any cold working operations (except shot peening or polishing) should be stress relieved prior to plating. This is done by baking the parts at 350 to 400 °F for ½ to 3 hours just prior to the final preparatory steps before plating.

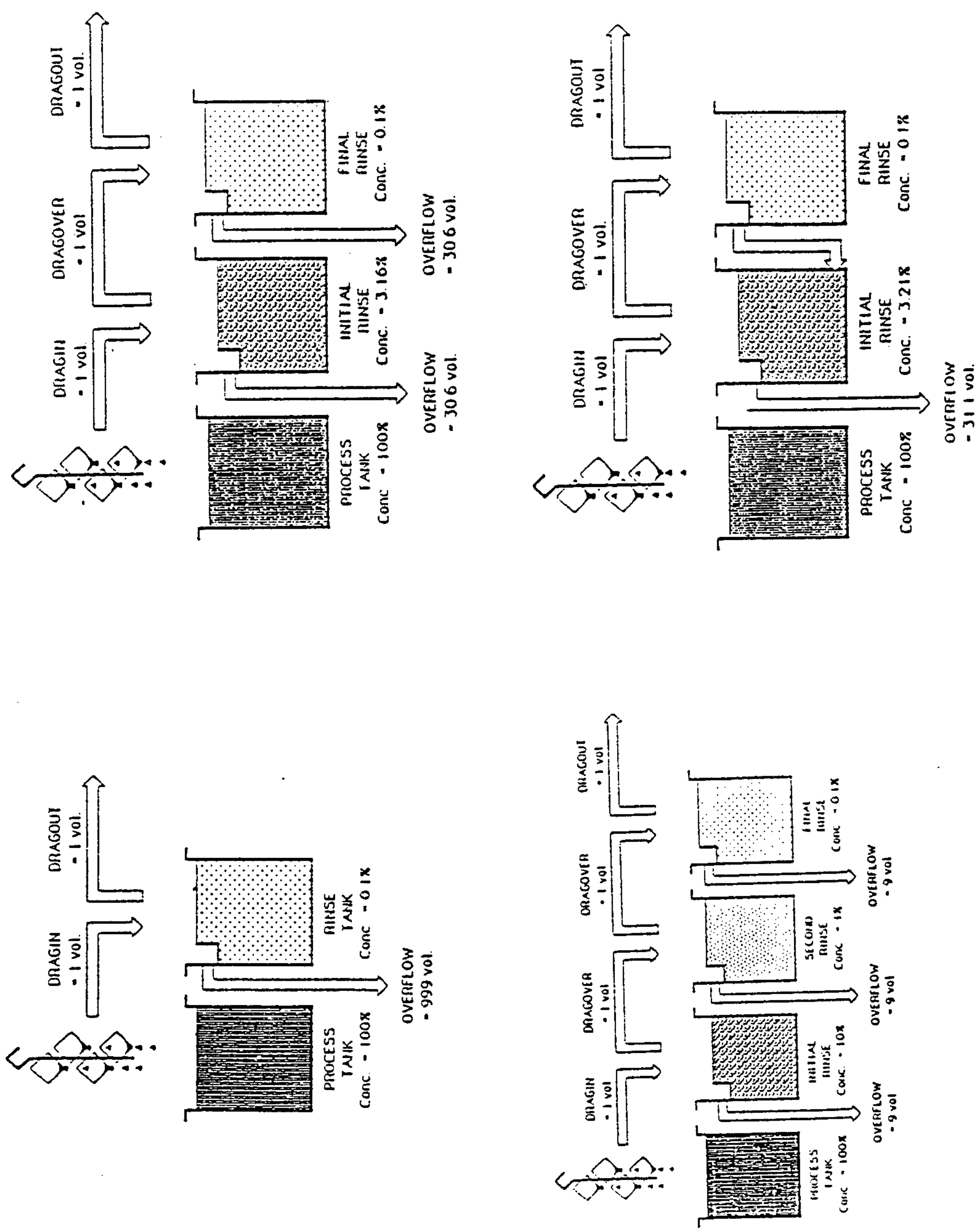
***5.5.2.1.5* Mask and Tape**. Many applications require that specified areas of a part not be plated. These areas are covered with resists or "stop offs" to prevent local plating. Common "stop-off" materials are tapes, lacquers, wax, and other materials. In addition, shields and robbers are used in chromium plating because of high current densities. The purpose of the electrical robber is to prevent burning or excess build-up of plating on corners and edges. A robber is usually a length of steel wire or rod that is attached electrically to the part being plated. It receives a plate, which otherwise would have built up on the edge of the work piece. A shield is an insulating material used to alter the distribution of the electric field between the anodes and cathodes (parts).

5.5.2.1.6 **Rinsing**. In general, rinsing is necessary to remove the process solution from the work between the various treatment stages. For example, parts carrying off an unrinsed film of alkaline cleaning solution would quickly contaminate the plating bath. Subjecting the work to a high level of contamination in the rinse tank can also cause passivation of the work surface or encourage precipitation of reaction products on the work. Also, if the final processing solution is not properly rinsed, salt spotting will occur, which may cause etching or otherwise harm the quality of the finished part.

The dilution ratio usually required in rinse tanks is 1000:1. Different process layouts are used for rinsing. It can be performed in one, two, or three stages, where the concentration in the tanks is reduced from tank to tank, finally reaching the desired 0.1 percent of concentration in the last tank. Figure 5 shows how the amount of wastewater in overflow can be reduced by increasing the number of rinsing steps. Figure 5 also shows the use of a technique called “Counterflow Rinsing,” in which the water overflowing from the final rinse is used as the input for the initial rinse.

5.5.2.1.7 **Etch**. Etch for non-corrosion-resistant steel is performed in a chromic acid bath. Parameters are: 1 to 2 A/sq in., temperature from room to 130 °F, and required time from ½ to 5 minutes. Etching in plating solution increases the iron contamination in the plating bath. Corrosion-resistant steel should be cathodically treated in sulfuric acid solution at 5 to 6 volts and ambient temperature for 2 to 3 minutes. A thorough rinse is required.

5.5.2.1.8 **Process Chemistry**. For hard chromium plating, three basic formulations are used. All three use chromium trioxide (CrO_3) as the source of chromium. When CrO_3 is dissolved in water, chromic acid is formed. The sulfate ion (SO_4) is also necessary and is usually introduced as sulfuric acid or as a salt such as sodium sulfate. In the conventional chemistry of the chrome plating process, these are the only constituents. The chromic acid is present in concentrations of 20-60 oz/gal.



A–single stage; B–double rinse; C–triple rinse; D–counteflow rinse

Figure 5. Water rinsing diagram.

The sulfate concentration is critical and is always held in a ratio relative to the chromic acid concentration. A CrO_3/SO_4 ratio of 100/1 is the most common. At lower ratios such as 80/1, smoother deposits are obtained, but throwing power and covering are reduced. At ratios of up to 130/1, the opposite characteristics are found. At even higher ratios, dull deposits and slower plating rates are obtained. Several proprietary baths that automatically control the ratio are available.

Fluoride or mixed-catalyst plating baths have a higher plating efficiency, typically 20 to 25 percent versus 7 to 15 percent for conventional baths, and a harder, more wear-resistant deposit is obtained. In this chemistry, the chromic acid concentration may range from 20 to 50 oz/gal, with 28 to 33 oz/gal being the most common. The chromic acid to sulfate ratio is normally in the range of 150-250/1 for mixed-catalyst baths. The fluoride is commonly added as the $SiF_4^{=}$ ion in an amount of 0.25 to 0.4 oz/gal (2-3 g/L). This chemistry provides better activation for plating on bright nickel and is less susceptible to problems with current breaks than is the conventional chemistry. Two limitations of a fluoride-containing bath are:

- Exposed steel areas will be chemically etched by the bath during warm-up and plating times.
- This chemistry tends to build up iron contamination levels more rapidly than other nonfluoride baths.

A new fluoride-free chromium chemistry with the plating speed and physical-deposit characteristics similar to those of a mixed-catalyst bath is a proprietary bath with operating conditions of 33 oz/gal of chromic acid, 0.33 oz/gal of sulfate, 130 to 140 °F, and an efficiency of 20 to 26 percent. The chromic acid and catalyst levels are maintained by adding proprietary agents. This bath, being fluoride-free, will not attack exposed nonplated steel areas like a mixed-catalyst bath will.

Table 14 summarizes the recommended chemistries of each of these three systems in oz/gal. Data for the process used at CCAD are also presented.

5.5.2.1.9 Operating Conditions. Typical operating conditions for hard chromium plating are given in Table 15. Three tanks are used for hard chromium plating at CCAD, having capacities of 448, 448, and 168 gal. The hard chrome plating line also includes 5 tanks, each having a capacity of 524 gal, which are apparently used for other operations in the process (e.g., rinsing, etch, etc.).

Table 14. Chromium plating chemistries and solutions.

Chemical	Concentration (oz/gal)			
	Conventional[1]	Mixed Catalyst[1]	Fluoride-free[1]	CCAD[2]
CrO_3	33	32	33	34
$SO_4^=$	0.33	0.16	0.33	0.34
$SiO_6^=$	—	0.3	—	—
Proprietary catalyst	—		yes	—

Sources: 1 "Metal Finishing," 59th Guidebook-Directory Issue (1991).
2 Corpus Christi Army Depot Process Standard, "Hard Chromium Plating" (1992).

Table 15. Operating conditions of hard chromium plating baths.

Conditions	Conventional[1]	Mixed Catalyst[1]	Fluoride-free[1]	CCAD[2]
Temperature, °F	120-140	130-140	130-140	120-140
Cathode current density, A/sq in	0.25-2.5	1-4	1-6	1-3
Solution agitation	Optional	Optional	Optional	Once per shift and after standing longer than 4 hours
Anode/cathode ratio	1:1-3:1	1:1-3:1	1:1-2:1	No data
Anode material	Lead-tin(7%) alloy or lead-antimony (6%)	Lead-tin(7%) alloy	Lead-tin(7%) alloy	No data

Sources: [1] "Metal Finishing," 59th Guidebook-Directory Issue, 1991.
[2] Corpus Christi Army Depot Process Standard, "Hard Chromium Plating," 1992 Edition.

No data on the consumption of chemicals and electricity used for the hard chrome process and its variants were found in the literature to be able to compare the different process chemistries, but their different process efficiencies in terms of cathode current efficiency and plating speed are shown in the process data in Tables 16 and 17.

5.5.2.2 Shop Case Study. As a model for the estimation and analysis of the energy usage in an electroplating shop, the plating shop at Robins Air Force Base was considered for implementation in PEPR. Data are available for energy consumption for this shop as a whole. The data on steam consumption had to be analyzed to separate the steam used for heating from that consumed by process uses, primarily for heating solution tanks.

Table 16. Cathode current efficiency (%).

Current Density	Conventional Bath		High Speed Baths*	
A/sq in	130 °F	140 °F	130 °F	140 °F
1.0	10.9	10.8	15.0	14.2
1.5	12.4	12.0	18.5	17.9
2.0	14.0	13.6	21.4	20.6
3.0	16.3	14.9	24.0	23.4
4.0	18.1	17.0	26.0	25.3
5.0	19.4	18.2	26.8	26.2
6.0	20.7	19.3	27.5	27.0

* Mixed catalyst or fluoride-free

Table 17. Plating speed (in thousandths of an inch per hour).

Current Density	Conventional Bath		High Speed Baths*	
A/sq in	130 °F	140 °F	130 °F	140 °F
1.0	0.30	0.30	0.42	0.39
1.5	0.52	0.50	0.77	0.75
2.0	0.78	0.76	1.2	1.1
3.0	1.4	1.2	2.0	1.9
4.0	2.0	1.9	2.9	2.8
5.0	2.7	2.5	3.7	3.6
6.0	3.5	3.2	4.6	4.5

*Mixed catalyst or fluoride-free

The shop is modeled as a collection of tanks that may be categorized by their temperature of operation, ambient, warm, hot, and very hot. The steam consumption for each category of tanks was estimated from the losses that were estimated to occur during operation. Other uses of energy as individual energy-consuming operations are included in this model as well, e.g., ventilation (fan power and space heat for makeup air), electricity for electric ovens and plating tanks, etc.

5.5.3 Energy and Emissions Data and Issues

5.5.3.1 Energy Usage and Conservation Measures. Energy is usually used in plating shops in the form of steam and electricity. Steam is usually used to heat the plating and rinse solutions that must be used at an elevated temperature.

Electricity is used to power lighting, air handlers, scrubber fans, air compressors, blast cabinets, ovens, filtration equipment, pumps, rectifiers, and other miscellaneous equipment. A large portion of the energy used in plating shops is consumed in the shop taken as a whole, as a fixed amount of consumption with little apparent variation with production level. Plating solutions are frequently kept hot even when idle.

It is difficult to assign a specific amount of energy consumption to an individual operation or to calculate it on the basis of a unit product (e.g., per unit of plated area). Appropriate energy consumption and production data do not appear to be available to allow this calculation. The plating process itself for a batch of parts may require 2 to 3 days. Energy consumption is perhaps best considered on the basis of per hour of operation, and potential improvements compared on this basis, or on an annual basis.

Table 18 lists the individual process operations involved in the hard chromium electroplating process, typical operating conditions, estimates of steam consumption to maintain process-tank temperatures, and potential impacts of conservation measures. Steam is used in a hard chromium plating process for heating process and rinsing tanks. Several problems are common in the use of steam, and eliminating these problems can lead to a significant saving in thermal energy:

- The heated plating and rinse tanks should be insulated. The losses through uninsulated walls can be significant, and a thickness of insulation of only 1 in. can reduce wall heat losses by about 90 percent.
- Solution surfaces should be covered with a layer of floating balls to reduce evaporation and mist formation, thus conserving energy.
- Insufficient and deteriorated insulation covering steam lines. A rigid glass foam or aluminum encased insulation should be used instead of fiberglass insulation.
- Leaks in steam lines and coils should be located and fixed. Such leaks not only reduce energy efficiency, but also present safety hazards and increase the ambient temperature in the shop.

Proper maintenance and efficient operation of major processes are the key measures for savings in electricity. Two major recommendations for the electrical equipment employed in the plating process directly are aimed at plating-tank power-supply units and electric ovens for stress relief and baking:

Table 18. Estimated steam consumption in hard chrome plating operations.

Process Operation (assumed tank size[1])	Typical Operating Conditions	Estimated Consumption of Thermal[2] and Electrical[4] Energy (Btu/hr)	Potential Impacts of Energy Conservation Measures
Vapor degreaser[3]	165 °F	4,000 thermal	Several measures possible to improve operation with respect to solvent loss, probably little impact on energy consumption per se.
Alkaline cleaning (insulated and ventilated)	180 °F max.	131,120 thermal	Cover solution surface with balls to cut thermal energy losses by 55,000 Btu/hr.
Stress relief in oven	400 °F max.		
Rinsing	room temp. to hot		
Etch (insulated and ventilated)	13 °F max.	41,000 thermal	Cover solution surface with balls to cut thermal energy losses by 15,500 Btu/hr.
Chrome plating (insulated and ventilated)	14 °F max.	51,680 thermal 24,600 electrical	Cover solution surface with balls to cut thermal energy losses by 19,900 Btu/hr.

1 Average tank size at RBAFB—4-ft width x 8-ft depth x 10' length.
2 Factors for tank heat losses taken from *Metal Finishing Guidebook and Directory* (1991).
3 Assumed 60-lb load every 10 minutes, heated to 165 °F.
4 Assumed conditions: 9 V, 2 A/in^2, 60-lb load with area to be plated of 400 in^2; a significant portion of this electrical energy probably ends up heating the solution.

- Rectifiers should be used as DC power supply units for electroplating rather than the older motor-generators (MG). Rectifiers are more energy efficient (87.0 to 99.7 percent efficient) because they convert AC electrical energy directly into DC electrical energy. MG sets have an intermediate mechanical conversion step that reduces energy efficiency.
- Ovens should be of newer design, with energy-efficient construction. The condition of their doors and seals is very important, because the misalignment of doors and the inelasticity of seals can lead to significant heat losses.

5.5.3.2 Pollution Generation and Prevention. Processes involved in hard chromium plating generate all types of pollution: solid waste, air emissions, and liquid waste. Plating-shop pollution is generated in four common ways: (1) dragout of chemicals on parts and fixtures which is carried into rinse water and/or subsequent process tanks, (2) chemicals lost through the tank fume exhaust system that are discharged to scrubbing systems or the atmosphere, (3) dumps of contaminated and/or depleted process chemicals, and (4) process tank overflows, which often occur when water is added to make up evaporative losses.

Different measures can be taken to reduce or prevent pollution, such as waste reduction, reagent or process substitution, waste recycling, and other process modifications. The implementation of process modifications leading to greater productivity will reduce the amount of pollution per part plated, and very often the same measures will decrease the amount of energy used per unit product. A brief analysis of pollution generation sources and possible reduction measures follows.

***5.5.3.2.1* Air Pollution**. Hydrogen is formed on the cathode. Gas evolution reduces solution efficiency and creates air pollution when discharged. The quantity of metal plated versus the amount of gas discharged is known as the process "efficiency." When the efficiency is low, the process generates a lot of gas and often requires an additional ventilation and scrubbing system. Scrubbing systems generate waste unless specifically designed to use recycling. The efficiency can be maximized by use of good agitation, but air agitation should be avoided if possible. Cathode efficiency can be improved by operating at the upper end of the allowable temperature range.

Another effect of hydrogen discharge is the formation of chromic acid aerosol/mist, which is drawn into the exhaust system. Most shops employ wet scrubbers to remove the chromic acid from the air stream. The chromium is transferred from the air to water, which must be subsequently treated. Good conservation can be practiced by using mist eliminators instead of wet scrubbers. In a mist eliminator, mist is captured by chevron plates or mesh pads, and washed down. The resultant concentrated solution can be recycled back to the plating tanks.

***5.5.3.2.2* Anode Sludge/Waste**. A reaction on the anode creates an oxide film on its surface; the anodes become passive. This film must be cleaned off with a strong acid pickling solution. This cleaning operation can generate a significant amount of waste. Anode passivity can also result in more solids being introduced into the plating solution, reducing the life of the filter which purifies the working solution. Anode efficiency can be improved by:

- keeping hooks clean
- maintaining correct anode surface area
- using good agitation
- controlling the temperature
- using the correct anode for the process.

One good example of equipment modification to re-engineer the electroplating process for increased efficiency and productivity is the use of conforming anodes as in the Innovative Hard Chrome Process (IHCP). Conventional hard chromium plating uses a set of stick anodes that are positioned around parts in the chrome plating tank. Some anodes are closer to a part than others, which creates a nonuniformity in the electrical field. This process plates slowly (<0.001 in/hr) and unevenly. Conforming anodes are made from lead alloy mats that are cut and shaped to conform to the surface of the part being plated. The closeness and even distance provide faster plating (0.004 in/hr) and a more even deposit.

The use of conforming anodes reduces the overall plating time, permits a much higher loading of chrome plating tanks, reduces emissions, and saves energy. However, one drawback is that an inventory of conforming anodes must be maintained for the parts of various shapes and sizes expected in the shop.

***5.5.3.2.3* Rinsing**. Pollution associated with rinsing is created in two ways: dragout of working solutions from process tanks, and wastewater from rinsing. Inefficient rinsing (e.g., the use of single immersion rinsing) can also lead to product quality problems, such as spotting and poor adhesion. The following measures are recommended to reduce the quantity of pollution from rinsing, improve rinsing efficiency, and improve product quality:

- The tank layout should provide linear sequencing to prevent cross-contamination of solutions and dripping.
- Tanks should be located as closely together as possible with drip guards between the tanks.
- Multiple rinses should be used after each process tank to reduce the amount of clean water needed for good rinsing.
- Timer rinse control should be installed on all rinse systems to control the flow of rinsewater.
- Chemical recovery technologies should be used with all low- and ambient-temperature process baths to recover dragout.
- Agitation should be used in all rinse tanks to improve rinsing efficiency.
- Reactive rinsing should be used on all lines where rinsewater used after acid cleaning is reused for rinsing after alkaline cleaning.
- Rinse tanks should be designed to reduce short-circuiting of rinsewater.

5.5.4 Energy Conservation Opportunities (ECOs)

The ECOs that have been identified for electroplating shops are listed in Table 19. The quantitative data for those ECOs for which this information is available or had been estimated and put into PEPR are also shown, as well as the results of the analysis by the PEPR software.

Table 19. List of ECOs and re-engineering suggestions for electroplating processes and shops.

Description of ECO	Capital Cost ($)	O&M Saving ($/yr)	Energy Saving MBtu/yr	Payback yr	Return on Investment, %	Savings-to-Investment Ratio (SIR)
ECOs in PEPR Software						
Reduce 100-percent overplating to 50 percent.	na	na	466 689[2]	---	---	---
Replace air agitation with electric agitation in tanks.	140,000	na	3,128 4,320[2]	2.2	14.6	6.97
Float polypropylene balls on top of solutions to reduce heat losses.	2,500	na	5,568 10,630[2]	0.1	[1] 77.7	212
Eliminate use of steam for heating tanks and replace with natural gas.	155,000	na	-1,497 10,738[2]	4.4	[1] 12.4	4.71
Non-quantified ECOs						
Install plating waste concentrators to recover and recycle waste solutions.						
Supply gas to power washers for heat instead of electricity.						
Replace use of central compressed air with low-pressure air.						
Install variable frequency drives on exhaust ducts.						
Install automatic dampers to close exhaust ducts.						
Consider installing countercurrent rinsing tanks.						
Optimize the batch size.						
Re-engineering Suggestions						
Consider using conforming mat anodes.						
Consider using more efficient process chemistries.						

[1] Energy saved at the process.
[2] Energy saved in primary fuel, considering losses in central steam and compressed-air supply systems, and efficiency of steam generation.

5.5.4.1 Reduce 100-Percent Overplating. Frequently, parts are overplated up to 100 percent to allow for an adequate thickness for uniform grinding. However, this amount of overplating would appear to waste energy and materials; overplating should be controlled at a lower level, e.g., 50 percent, for conservation.

5.5.4.2 Replace Air Agitation with Electric Agitation in Tanks. Compressed air is typically used to agitate solutions in plating tanks. Although the use of compressed air for this purpose is convenient, compressed air is very energy inefficient. Electric agitators should be considered to eliminate the use of compressed air for this purpose.

5.5.4.3 Install Plating Waste Concentrators To Recover and Recycle Waste Solutions. Waste plating solutions are usually sent to the industrial wastewater treatment plant. A better idea is to recycle these solutions by concentrating them; the concentrate is returned to the plating tank and the water is returned to the rinse tank.

5.5.4.4 Supply Gas to Power Washers for Heat Instead of Electricity. Natural gas is a cheaper source of energy to use for heating the washwater than is electricity. Power washers (except perhaps for small washers) can usually accept this source of energy for this purpose, possibly with a small additional capital expense for this option.

5.5.4.5 Float Polypropylene Balls on Top of Solutions To Reduce Heat Losses. Uncovered, hot solutions in plating tanks can lose a significant amount of energy through increased evaporation and heat loss. Balls floated on top of the hot solutions in heated tanks can reduce these heat losses significantly (a factor of perhaps half).

5.5.4.6 Replace Use of Central Compressed Air With Low-Pressure Air. Compressed air is used in plating shops for a variety of uses, such as cleaning and drying parts, and especially for agitating the tanks. However, these uses do not require 100-psi air from the central compressed-air supply. Central compressed air is typically throttled before it is used in plating shops. It would be more efficient to generate low-pressure compressed air on site within the shop for any necessary use of compressed air.

5.5.4.7 Eliminate Use of Steam for Heating Tanks and Replace With Natural Gas. The use of steam, particularly the 125 to 150 psi steam from the central steam supply with all of the inefficiencies of that system, is an inefficient and unnecessary way to heat the solutions in plating tanks. Systems are available to use natural gas for heating plating tanks directly, with an individual burner system and temperature control for each tank.

5.5.4.8 Install Automatic Dampers to Close Exhaust Ducts. Plating shops typically have a large number of exhaust fans and ducts; each hot tank has a ventilation duct that collects fumes and emissions. However, whenever a tank is unused and its fan is turned off, a draft through the open duct causes energy to be lost. A damper that would close automatically if the fan is de-energized would prevent this draft loss.

5.5.4.9 Install Variable Frequency Drives on Exhaust Ducts. The ventilation load in a plating shop varies as a function of how many tanks are used at any one time. It is inefficient and wastes energy to keep the ventilation fan running at a constant speed. If the fan is equipped with a variable frequency drive, the fan speed can vary in response to the load, saving energy.

5.5.5 Re-Engineering Suggestions

The specific ideas for improving the operation of the hard chromium electroplating process discussed above are:

1. Insulate the hot plating tanks to reduce heat losses, and cover solution surfaces with balls to reduce heat and evaporation losses.
2. Investigate the re-engineering of the process to use the innovations of the IHCP for improved throughput, such as using conforming mat anodes, more efficient process chemistries, zero discharge rinsing, and bath purification.
3. Examine the layout of the tanks for improved efficiency in process flow.
4. Improve the rinsing operation by using multiple rinses and other measures.
5. Examine the ovens for energy conservation opportunities such as improved insulation and seals and reduced warm-up times.
6. Investigate the use of rectifiers as DC power supply units for electroplating rather than the older motor-generators (MGs).

5.6 Heat Treating

5.6.1 Introduction

Heat treating is a very common unit operation at Army industrial facilities. Heat treating is used in the production of forgings and metal parts. It is used to process finished products for a variety of reasons, and it is used to anneal metal parts such as the case and the bullet jacket for small-caliber ammunition. It is carried out in a number of different types of ovens and furnaces, which may be heated with electricity, steam, or the direct combustion of fuel. A variety of process conditions of time and temperature are used, depending on process requirements. The variety of furnace types, process conditions, fuels, and operating procedures means that a variety of specific energy conservation measures are possible, depending on the specific heat-treating situation.

As described below, there appear to be a number of energy conservation measures that can be implemented for heat-treating furnaces to reduce energy consumption. These include insulation, and better control of the combustion process in gas-heated furnaces. In addition, some recent work at Rock Island Arsenal to study the requirements of the heat-treating process indicates that the length of time required for treatment in a furnace for the internal temperature within certain types of metal parts to reach the desired level can be reduced, thus increasing the production rate of the heat-treating equipment and reducing the per-unit-product amount of energy consumption. This type of study could perhaps be carried out for many of the various heat-treating operations in Army industrial processes to see if the length of time for heat treating and therefore the energy consumption can be reduced by this simple measure.

Two examples of typical heat-treating operations illustrate some of the diversity of heat-treating processes in Army facilities:

1. Annealing furnaces used in manufacturing cases for small-caliber ammunition
2. A typical quench-and-temper heat treatment of ferrous metal parts.

5.6.2 Examples of Heat Treating Processes

5.6.2.1 Annealing Furnaces. The conventional process for manufacturing small-caliber ammunition such as the 5.56-mm cartridge, as carried out at Lake City Army Ammunition Plant, includes a number of annealing operations. Annealing is done on the case after each of several draw-and-turn steps, a total of four annealing operations out of a total of 21 process steps. Three of the four annealing steps are carried out in an electrical annealing furnace. The final "mouth and neck anneal," which is the largest single energy consumer in the process at 16.9 percent of the total process energy, is done in a gas-heated furnace that appears to present some opportunities for energy conservation. The "body anneal" is the second largest energy consumer at 11.3 percent of the total process energy consumption.

In the manufacture of the bullet, the first operation is a "cup anneal," which is carried out in a gas-heated annealing furnace. Table 20 summarizes the energy consumed in these annealing operations in the production of 5.56-mm cartridges at Lake City.

Table 20. Energy consumption in annealing operations in manufacturing 5.56-mm cartridges at Lake City.

Annealing Operation (number of machines)	Energy Consumption per Round Btu/round		Energy Consumption for Normal Production of 3600 Rounds per Minute Btu/hour	
	Natural Gas	Electricity	Natural Gas	Electricity
Case:				
First Anneal (1)	—	2.8	—	603,000
Second Anneal (1)	—	1.9	—	406,900
Body Anneal (8)	2.8	4.3	600,000	927,200
Mouth and Neck Anneal (30)	10.4	0.14	2,250,000	30,000
Bullet:				
Cup Anneal (1)	1.2	0.08	253,000	17,065

***5.6.2.1.1* Electrically Heated Furnaces**. Several of the annealing steps for case manufacture are carried out in electrically heated annealing furnaces, e.g., a Westinghouse anneal machine for the "first anneal" and the "second anneal." The equipment for the "body anneal" was not described, but it apparently used some gas as well as electricity for heating.

***5.6.2.1.2* Gas-Heated Furnaces**. The "mouth and neck anneal" operation in case manufacture is done in a Modern Bond annealing furnace, but no additional descriptive information was available on this equipment. The gas consumption was simply estimated rather than calculated from a heat balance. No data were given on process conditions.

The gas-heated annealing furnace used for the "cup anneal" step in bullet manufacture is a Salem Engineering annealing furnace, with dimensions of 15 ft long, 6 ft wide, and 6 ft high. The material is heated from 77 to 280 °F in the annealing process. The standard production rate is 3600 rounds per minute (216,000 rounds per hour or 4,630 lb/hr of brass through the furnace).

With respect to energy conservation, this furnace appears to have a number of opportunities:

1. The sides and the top apparently are not insulated; the heat lost (85,200 Btu/hr) is estimated at 34 percent of the total heat consumed by the furnace.
2. There could also be better seals on the furnace outlets.
3. As a fuel combustion system, the combustion process in the furnace needs to be controlled, specifically, for excess air. In one reference, these furnaces at Lake City are cited as being operated at 666 percent excess air, as opposed to a recommended level for boilers of 7 to 15 percent. Thus, the installation and the use of fuel-to-air-flow ratio controllers is indicated.

4. Energy usage per unit product can be minimized by using full loads in the annealing furnaces since energy consumption is a function primarily of operating time rather than production rate.

Lake City has approximately 18 gas-heated annealing furnaces. Energy savings could be substantial if these measures were implemented on all of these furnaces.

5.6.2.2 Quench-and-Tempering of Ferrous Metal Parts. In the heat-treating shop at Anniston Army Depot, one of the most common heat-treating operations is a two-step quench-and-temper operation to treat ferrous metal parts. The purpose of the process is to impart the desired properties to the part by changing the carbon content of the surface metal through treatment in a controlled atmosphere at high temperature. The process uses two furnaces: (1) an integral quench furnace (Atmosphere Furnace Company Model UBQ-364830), which can go up to a temperature of 2000 °F, and (2) a draw furnace (also an Atmosphere Furnace), operated typically at 800 to 1200 °F. Both furnaces operate on natural gas.

Because both furnaces are constructed of firebrick, they are kept on all the time to minimize temperature cycling of the firebrick. They are turned down on weekends (1450 °F or so for No.1 and 300 °F for No. 2—No. 1 cannot be turned down below 1400 °F or else the controlled atmosphere will be affected). No. 1 is indirectly heated with combustion of natural gas; exhaust gases are at 1500 to 1600 °F. No. 2 is directly heated with natural gas; the exhaust is at the temperature of the furnace atmosphere.

In the quench-and-temper process, a part is heated in the No. 1 furnace at 1600 °F for a specified time (typically in the range of 1-2 hours) and then quenched in the oil bath, which is an integral part of the furnace. The part is then stress relieved in the No. 2 furnace by being treated at around 1000 °F for another 1 to 2 hours or so, after which time it is allowed to cool.

5.6.3 Energy and Emissions Data and Issues

5.6.3.1 Energy Usage in Ovens and Furnaces—General. The data in Table 20 for annealing operations at Lake City are energy consumptions estimated in various ways, rather than the result of complete and detailed data collection efforts. As a result, they lack detail, and some possible energy conservation measures may be overlooked in examining these data by themselves.

An oven uses energy in several different ways, in addition to the main area of consumption—keeping the oven space at the required temperature. For example, air may be circulated within the heated space to ensure a uniform temperature, requiring a recirculation blower using, for example, a 1-1/2 to 3 hp motor. There is perhaps an exhaust blower, run by a 1/2-hp motor, to remove products of combustion and volatile vapors from the oven during heating. In standard oven designs, this make-up air stream may be about 20 percent of the circulation rate. It would be help reduce energy consumption if: (1) these motors were of the high-efficiency type, and (2) the make-up air stream were to be controlled at a minimum value determined as the result of an analysis of the actual requirement for make-up air for the specific application.

In a standard oven design, the make-up air stream at the 280 °F temperature of the annealing furnaces described above may contain 78,000 Btu/hr or more. Can this hot exhaust air be heat-exchanged with some cold stream that must be heated, or can this stream of hot air be reduced in amount? The amount of energy consumed by the oven to keep itself at a constant temperature may be estimated as being proportional to the temperature difference between the (high) desired temperature and ambient. Therefore, energy can be conserved by using good instrumentation and controls to keep the temperature constant and only as high as is actually necessary.

5.6.3.2 Energy Usage in Firebrick Furnaces. As indicated in the discussion above on the quench-and-temper process, some furnaces constructed of refractory firebrick are kept hot all the time to minimize the effects of temperature cycling of the firebrick. The energy concerns associated with these types of furnaces are similar to those of furnaces that can be turned off and on, but there are some unique aspects as well. Since these furnaces have a constant hot exhaust stream, there is a significant opportunity to recover heat on a constant basis, especially with gas-fired furnaces with indirect heat. In this type of furnace, the hot combustion gases are used to heat the furnace via radiant tubes with the exhaust flue gas being emitted at a very high temperature. With this type of design, the objective is to keep the combustion gases separate from the furnace atmosphere.

5.6.4 Energy Conservation Opportunities (ECOs)

Table 21 lists the ECOs identified for heat treating processes. The quantitative data for those ECOs for which this information is available or has been estimated and put into PEPR are also shown, as well as the results of the analysis by the PEPR software. Appendix B.5 includes details of the quantified ECO analyses.

Table 21. List of ECOs and re-engineering suggestions for heat treating processes.

Description of ECO	Capital Cost ($)	O&M Saving ($/yr)	Energy Saving MBtu/yr	Payback yr	Return on Investment, %	Savings-to-Investment Ratio (SIR)
ECOs in PEPR Software						
Install improved seals on furnace doors (quench furnace).	4,600	na	59	16.0	5.4	1.31
Install improved seals on furnace doors (draw furnace).	4,600	na	27	34.6	1.4	0.61
Design heat recovery system to use hot exhaust for preheat (quench furnace).	15,500	na	26	123	-4.8	0.17
Apply ceramic coating to firebrick (quench furnace).	12,600	na	1,174	2.2	16.4	9.57
Apply ceramic coating to firebrick (draw furnace).	12,600	na	456	5.6	11.0	3.71
Install recuperators on gas-fired (indirectly heated) furnace (quench furnace).	13,000	na	929	2.9	14.9	7.34
Schedule production and leave unneeded furnaces turned off—for example, leave both furnaces at ANAD turned down two extra days per week.	0	na	1,060	—	—	—
Non-Quantified ECOs						
Use full loads in furnaces.						
Provide regular maintenance for gas-fired furnaces.						
Consider converting electric ovens/furnaces to natural gas.						
Determine if the standard amount of exhaust and make-up air provided for in the oven design can be reduced.						
Re-Engineering Suggestions						
Search for a possible need for thermal energy to supply by heat-exchanging with the hot exhaust from the oven.						
Review standard operating procedures to see if the recommended heat-treatment temperature and time to produce the desired quality in the product can be reduced.						
Investigate the possible use of newer types of ovens.						

5.6.4.1 Install Improved Seals on Furnace Doors. Since a furnace operates at a temperature higher than ambient, air may be drawn into the combustion chamber through any cracks and crevices due to the stack effect. Such air allowed to infiltrate into the furnace is detrimental to the furnace efficiency. Energy can be saved by using effective door seals. The quench and the draw furnaces are analyzed separately for this ECO because they operate at considerably different average temperatures.

5.6.4.2 Design Heat Recovery System To Use Hot Exhaust for Preheat. Heat can conceivably be recovered from hot furnace exhaust gases by using them to preheat cold charges prior to heat treatment. The hot exhaust gases would be ducted into an insulated chamber containing the cold charge before being loaded into the furnace. The same type of insulated chamber could be used to prevent heat losses from hot charges (works-in-process) from being dissipated into the shop atmosphere between processes. A system is analyzed here for the quench furnace because its exhaust is at a much higher temperature than that of the draw furnace.

5.6.4.3 Apply Ceramic Coating to Firebrick. Spray-on ceramic coatings can increase the surface emissivity of the refractory surface to above 0.95. The increased radiative transfer resulting from this increased emissivity can yield savings in fuel. Although such savings cannot be accurately quantified, energy savings from this measure are conservatively estimated as 15 percent of burner fuel input. The quench and the draw furnaces are analyzed separately for this ECO because they operate at considerably different average temperatures.

5.6.4.4 Install Recuperators on Gas-Fired Furnace. The No. 1 furnace at Anniston is indirectly heated with gas. The exhaust has a high temperature, typically around 1600 °F, and thus contains a great deal of heat now lost to the atmosphere. The most cost-effective system for capturing some of the waste heat in the exhaust is to install a recuperator to preheat the combustion air. The furnace manufacturer makes recuperators for this furnace for this purpose, which are sold as an option.

Each recuperator for this furnace (one recuperator is needed for each of six radiant-tube heaters in the furnace) costs $1,500. The total cost for the recuperation system is then $9,000 plus installation. The savings in energy can be as high as 50 percent of the waste heat contained in the exhaust stream.

5.6.4.5 Schedule Production and Leave Unneeded Furnaces Turned Off. In a typical heat-treating shop, all the furnaces are turned up from their weekend temperatures the first thing on Monday morning to be at operating temperature at all times during the week whenever a job is received. (At the end of the work shift, they may be turned down somewhat, depending on each furnace's characteristics.) If it were known ahead of time what jobs would be received during that day or week, then furnaces not needed for the anticipated production load could be left off, thus saving a great deal of energy without any capital expenditure.

As an example of the potential savings, the quench and draw furnaces at Anniston were analyzed for this change in operation. To save energy these two furnaces at Anniston are turned down on weekends. Then they are turned up to temperature at the beginning of the week. However, the production logs indicate that at the present time these furnaces are not used every day, and when they are used, there may be only one job a day (at 1-2 hours for each furnace). Energy could be saved in these furnaces without incurring any capital cost simply by scheduling their use and perhaps bunching batches of parts together for treating at the same time or at least on the same day.

Thus, a system of scheduling production should be set up so that the next week's production is known in advance. If insufficient work is anticipated, then the furnaces can be left turned down on the weekend schedule for Monday and Tuesday, etc. Although it would be best to schedule production for this purpose, the furnaces could simply be left turned down on Mondays and Tuesdays, so that jobs requiring the use of these furnaces would be naturally bunched together in the remaining days of the week.

5.6.4.6 Provide Regular Maintenance for Gas-Fired Furnaces. Although gas-fired furnaces can be cheaper to operate than electrical furnaces because gas is cheaper than electricity, gas-fired furnaces do benefit from regular maintenance. Regular maintenance is necessary to adjust the combustion conditions to their peak efficiency. For example, the optimum air-to-fuel ratio is a function of gas composition, which changes over time as a result of composition changes in gas from different suppliers.

5.6.4.7 Consider Converting Electric Ovens/Furnaces to Natural Gas. Gas-fired furnaces can be cheaper to operate than electrical furnaces because thermal energy obtained from gas is cheaper than that obtained via electricity. This ECO is not applicable to the furnaces used for quench and temper at Anniston.

5.6.4.8 Use Full Loads in Furnaces. Since the amount of energy required to keep a furnace at a constant temperature is not a function of the load inside, the amount of energy per unit of material treated can be reduced by putting a full load in the furnace, rather than only a partial load. For example, for two jobs of half a furnace load apiece, rather than one full-load job, the furnace must be run for two cycles rather than only one. For the type of furnace which is always left on, such as those used for quench and temper at Anniston Army Depot, using a full load is not as important.

In a job type of heat-treating shop, the objects in the shop to be treated at any one time may require different conditions, so that it may be difficult to consolidate different jobs to always have a full load. However, this situation could be helped if production were scheduled with this principle in mind, rather than simply treating every job whenever it is received in the shop.

5.6.5 Re-Engineering Suggestions

5.6.5.1 Newer Types of Furnaces for Heat Treating. For heat treating metals, there are newer types of ovens and furnaces that may be used. These newer systems, which include induction furnaces, are more energy-efficient and therefore should be evaluated for possible application to Army processes. Table 22 lists some data for comparing different types of furnaces, taken from a data base on industrial electric end-use technologies from the Electric Power Research Institute.

5.6.5.2 Summary of Improvement Options. The specific ideas for improving the operation of heat-treating ovens and furnaces discussed above are the following, ranging from refurbishing the oven and its operation to defining new operating conditions to reduce energy consumption per unit product:

1. Review standard operating procedures, including recommended warm-up time, and turn off (or leave turned down) the oven or furnace when not needed for scheduled production.
2. Analyze the operation of furnace combustion systems to determine that they are operating properly with respect to excess air, etc.
3. Examine physical condition of oven or furnace for proper insulation, condition of seals, and possible need for improved instrumentation and control system.
4. Review standard operating procedures to see if the recommended heat-treatment temperature and time are really necessary to produce the desired quality in the product, doing research if required, and reduce the temperature and time for treatment, if possible.
5. Analyze the standard amount of exhaust and make-up air provided for in the oven design, and determine whether this amount of make-up air can be reduced.

Table 22. Relative energy performance by furnace type.

Furnace Type	Energy Type	Energy Input Btu/Ton of Steel	Efficiency %
Indirect resistance	Electricity	701,000	60
Induction	Electricity	616,000	72
Gas furnace	Thermal (gas)	2,110,000	21

6. Search for a possible need for thermal energy to supply by heat-exchanging with the hot exhaust from the oven.
7. Install recuperators on gas-fired furnaces for preheating the combustion air, particularly those that are indirectly heated because they have a significant amount of hot exhaust.
8. Investigate the possible use of newer types of ovens.

6 Conclusions and Recommendations

6.1 Conclusions

1. The PEPR methodology for identifying process energy and pollution reduction opportunities requires collecting detailed information and data on process equipment and operations. The information required for a PEPR analysis is generally lacking in previous energy studies of Army industrial processes. The best way of collecting the required data for PEPR analyses and the process data base in the PEPR program is through site visits. Such visits should be done by personnel trained in PEPR procedures so that they collect the needed information on equipment specifications and process operations. Equipment specifications are extremely useful for estimating energy consumption, since, in most cases, energy data for individual process operations (or for the entire process) tend not to be available.
2. A program has been developed to help: (a) automate PEPR analysis procedures, and (b) collect and analyze process energy and pollution data for DOD industrial processes. The program was developed as a software screening tool for rapidly screening opportunities for conserving process energy and reducing pollution.
3. For the five types of processes studied to date using the PEPR methodology, a wide variety of opportunities for conserving process energy and reducing pollution have been found, ranging from no-cost changes in operational procedures, fuel and technology substitutions, and better process control, to re-engineering suggestions. Some of these ECOs could not be quantified since they require additional information to develop a useful initial analysis. The process re-engineering suggestions, almost by definition, require some work to test or develop them to a point where they can be analyzed for their continued consideration.

6.2 Recommendations

1. It is recommended that additional energy usage data and information on process equipment be collected by conducting additional site visits. This method appears to be the best way of collecting the required data for PEPR analyses.

2. It is recommended that an effort be made to collect data on the processes in the five categories studied to date to determine how many of these processes, and their variations, are at other Army bases. Data on the types and the numbers of these processes at other Army bases are essential to extrapolate the opportunities for energy conservation across the aggregate of Army industrial facilities.

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1. PEPR SYSTEM OVERVIEW

The PEPR system was developed by Science Applications International Corporation (SAIC) for the U.S. Army Construction Engineering Research Laboratory. The primary purpose of the PEPR system is to provide users with a flexible analysis tool for rapidly evaluating (screening) process energy and pollution reduction opportunities for industrial processes operated at U.S. Department of Defense (DOD) facilities. The system was developed using Microsoft FoxPro Version 2.6 for Windows, a Relational Data Base Management System (RDBMS).

1.1 Installing PEPR

To install PEPR on your computer's hard drive, you must have at least 4 megabytes of space available. Before attempting to install PEPR, check to see if there is enough room for it. To install PEPR on your hard drive, seven simple steps are required:

1. Make sure that Windows is running.
2. Place PEPR Disk 1 in drive A. If your source drive is drive B, improvise accordingly.
3. In Windows, choose the FILE option in the Windows Program Manager.
4. Pull down to the RUN option and select it.
5. When prompted, type in "a:setup". (Do not include the quotes.)
6. You will be provided with additional instructions while the setup routine is running (e.g., when to insert PEPR Disk 2, etc.). Follow all instructions carefully.
7. After the setup routine is finished, store the original PEPR diskettes in a safe place.

1.2 Hardware/Software Requirements

The system was developed using Microsoft FoxPro Version 2.6 for Windows. FoxPro is a Relational Data Base Management System (RDBMS) with a built-in programming language that allows for the development of custom applications. PEPR requires an IBM PC or compatible with an 80386 or higher microprocessor. It also requires approximately 8 megabytes of disk space as well as at least 8 megabytes of

RAM. The system was developed for a Windows environment and requires Microsoft Windows 3.1 or higher to run properly. It also was developed for use with monitors having VGA resolution. If the PEPR program is used with super VGA resolution, the program screen will not fit the monitor screen properly. In this case, the monitor resolution must be set up for VGA.

1.3 Analysis Scenarios

Upon execution of the PEPR system, an initial title window is displayed in the main PEPR window. Figure A1 shows this initial title window. This window is dismissed by pointing and clicking on the desired operation from the main menu located along the top of the window.

The central objective of most PEPR analyses will be to analyze a specific individual process or processes at a specific base, or perhaps to sum up the potential energy and pollution reduction opportunities for a number of processes found at a selected base. The capability to do these analyses will depend very much on having the requisite process data for the process or processes of interest already in the system data bases or collected and in hand ready to add to the system, as well as information on potential improved technologies and energy conservation opportunities that may be applicable to the subject process or processes.

The next section explains the various program operations that may be done with the PEPR software. Example scenarios of how these program operations are used to accomplish specific tasks and analyses are shown in the Annexes to this Appendix.

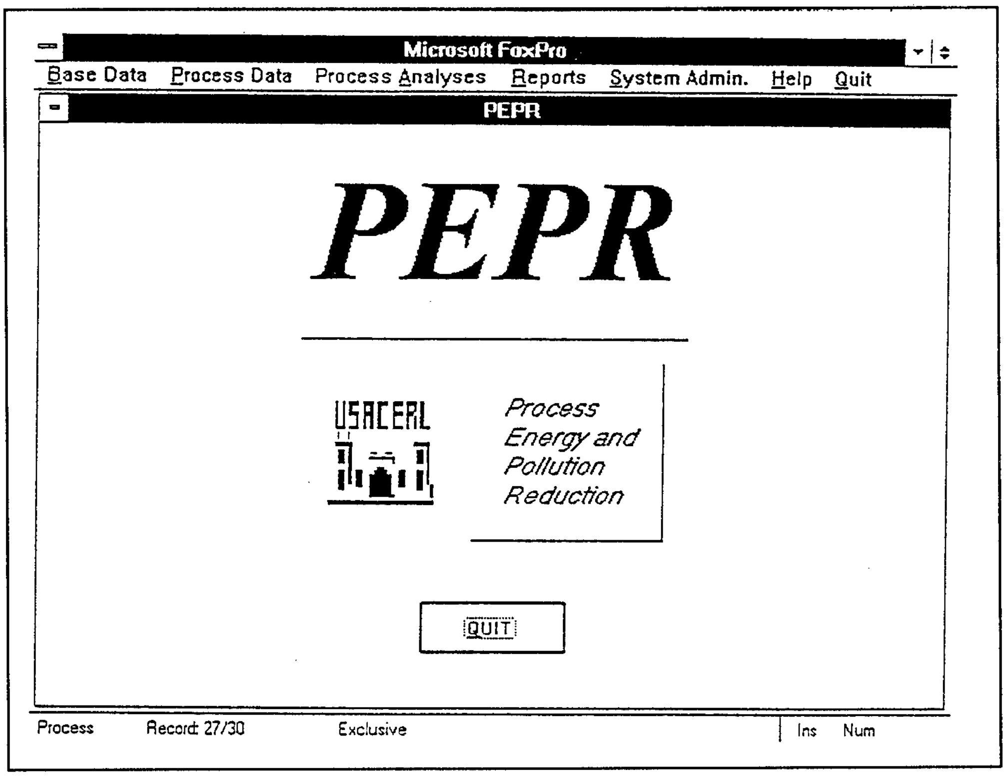

Figure A1. Initial PEPR title window.

2. PEPR PROGRAM OPERATIONS

The PEPR system is a flexible analysis tool that allows you to perform "what if" types of analyses. You may, at any time, make changes to any of the data in the system. The data for any of the bases and the processes, and parameter values for the process-expert routine and the improved technologies can be quickly modified, the analysis re-run, and the results displayed.

Warning. As is true with all computer systems, the GIGO (Garbage In - Garbage Out) principle applies here. If you enter numbers into the system that are unreasonable or you happen to mis-key a value, your results will not be reliable. Extra caution should be exercised when changing the data in this system.

As is shown in Figure A1, the main menu bar contains seven options—*Base Data*, *Process Data*, *Process Analyses*, *Reports*, *System Administration*, *Help*, and *Quit*. In the sections below, these main menu choices are explained in detail, as are the options on the submenus associated with each of these main menu options.

Note that the main menu options are independent of one another; it is not necessary to select these menu operations in any given order to accomplish a specific procedure. For example, the user interested only in performing process analyses based on the data already in the data base, can go directly to *Process Analyses* for analyses of specific processes or comparisons of improved with existing processes for a selected base, or *Reports* for summarized results from a number of process analyses or process comparisons.

2.1 Base Data

There is only one basic operation which you may perform under the *Base Data* option of the main menu bar. The main objective of this operation is to give the user access to the Base data base, either to review the data or to update them by either adding new bases or editing the data in the data base.

Base Data

When this operation is selected, a submenu appears, showing a list of the three services—*Army*, *Navy*, and *Air Force*. You must choose one of the three services to confine your operations to the appropriate section of the Base data base.

After a service has been selected, the program will then display a list of bases for the selected service—*Please Select a Base*—from which a base may be chosen by pointing and clicking with the mouse. After you confirm the choice by clicking on *OK*, the program will then open the Base data base at the record for the selected base with data displayed in the first data input screen. Clicking on *OK* without selecting a base will open the data base at the first base for the selected service. If you click on *Cancel*, you will return to the main menu.

From the first data input screen it is possible to perform any desired operation on the Base data base, using the buttons on the bar along the bottom of the screen. Thus, the record of interest can be found and viewed by either using the *First*, *Previous*, *Next*, or *Last* buttons, or by scrolling and selecting with the *Locate* function. In the Base data base, there are three data input screens. From the initial screen, the other data input screens for the same record may be viewed at will by pushing the *Page* button or buttons on the menu bar.

Add

A new record can be added to the data base by pushing the *Add* button on the first data input screen and filling in the blanks on the screen. To add information to a field, use the arrow keys or the mouse to highlight the field, and then type in the desired value. When finished with the first data input screen, use the *Save* button to save the changes to the data base or the *Cancel* button to cancel the added data. Access the second and the third data input screens by pushing the appropriate *Page* button. Push the *Edit* button, and make the desired additions to the data. Use the *Save* button on each input screen to save the changes to the data base or the *Cancel* button to cancel the added data on that screen.

Edit

A record that has been selected can be edited by pushing the *Edit* button and then making the desired changes. To modify the information in a field, use the arrow keys or the mouse to highlight the field, and then type in the desired value. Use the *Save* button to save the changes to the data base or the *Cancel* button to cancel the edits. When finished with the first data input screen, access the second and the third data input screens by pushing the appropriate *Page* button. Use the *Edit*, *Save*, and *Cancel* buttons on the second and the third data input screens in a similar manner as on the first screen to edit and save the edited data on each of these screens.

Warning. The data in the data base for base-name abbreviation should not be changed without exercising due caution. This information is used in the process data base to link processes to specific bases. The abbreviations in the data base have been determined to make each one a unique identifier of a specific base.

Delete

A base can be deleted from the Base data base by first locating its record on the first data input screen and then pushing the *Delete* button. A pop-up question will then appear asking for confirmation to delete the selected record.

Warning. Care should be exercised in deleting a base from the Base data base because processes in the Process data base are linked to specific bases. The process data will remain in the Process data base, but calculations that depend on base-specific data will become meaningless if the linked base is deleted.

Close

The data base is closed and the operation concluded by pushing the *Close* button, to return to the main menu.

2.2 Process Data

You may select from two operations under the *Process Data* option of the main menu bar: *Processes* or *Duplicate Process to Create Improved Process*. The main objective of the former operation is to give the user access to the Process data base, either to review the data or to update them by either adding new processes or editing the data in the data base. The main objective of the latter operation is to help the user create a new or improved process to add to the Process data base, by first duplicating a process already in the data base so that it can be easily edited with perhaps only a few changes being required to create the desired process.

Processes

If this operation is selected, a pop-up list appears—*Please Select a Process*—from which a process may be selected by scrolling through the list and clicking on the desired process. The process list includes all processes in the Process data base for all services. Each process, which is a unique record in the Process data base, is described in terms of process category, service, base, process name, process ECO, and production line. Existing processes are typically labeled as such in the process ECO column. After a process has been selected and the *OK* button has been pushed, the program will then open the Process data base at the specified process record with the general process data displayed in the data input screen. Clicking on *OK* without selecting a base will open the data base at the first process in the data base. If you click on *Cancel*, you will return to the main menu.

Note. When the Process data base is first opened, the data are grayed out (locked) to prevent any inadvertent changes being made in the data through random clicking on fields. The data can be viewed in this state. Pushing the *Add* or the *Edit* button at the bottom of the screen unlocks the data for subsequent operations.

From this screen it is possible to perform any desired operation on the Process data base, using the buttons on the bar along the bottom of the screen. Thus, any process record of interest can be found and viewed by either using the *First*, *Previous*, *Next*, or *Last* buttons, or scrolling and selecting with the *Locate* function. For the selected process, information on re-engineering suggestions contained in the data base can be reviewed by pushing the *Re-Engineering Suggestions* button. When finished reviewing the re-engineering suggestions, push the *Exit* button to close the screen and exit back to the general process data input screen.

From the initial screen showing the general process data for the selected process, you can move to the Operations data base showing the data for the individual operations comprising the selected process by pushing the *Operations* button. The data for any operation record of interest can then be found and viewed by either using the *First*, *Previous*, *Next*, or *Last* buttons, or by scrolling and selecting with the *Locate* function. For any selected operation record in the Operations data base, there are two data input screens, which may be viewed at will by pushing the *Page* buttons.

The HAP emissions associated with each process operation (and contained in the Emissions data base) may be viewed by pushing the *Emissions* button on the first operation data input screen. Any individual HAP emissions record can then be found and viewed by either using the *First*, *Previous*, *Next*, or *Last* buttons, or by scrolling and selecting with the *Locate* function.

On the general process data input screen beside a field labeled Scale Factor, there is a button marked *Scale Operation Data*. The purpose of this button is to scale the process data (material, energy, and emissions flows) that may have been put into the data base (1) on some basis other than per unit product—perhaps monthly or annual amounts, or (2) from a duplicated process. In either case, you must determine the appropriate value for the scale factor, which is put into the Scale Factor field, to scale the data to the basis of per unit product. Pushing this button will result in all the data on material, energy, and emissions flows for the process being *multiplied* by this factor, after which use the scale factor will be set to 1 by the program.

Note. The process data are to be stored in the data base on the basis of *per unit product* (final product from the complete process), and the data for the individual process operations must be consistent on this basis. However, the user has complete flexibility in defining what the unit product is. For example, it may be difficult to define a final product from some processes, or the energy consumption and the pollution generation may be related to the time of operation of the process rather than a final product per se. It is possible to define an hour of operation as the unit product, and enter the process data and analyze the process on this basis.

Finally, as an additional aid in analyzing the data, there is an *Analyze Process* button on the general process data input screen. Pushing this button will activate a series of calculations for calculating the total energy usage in producing a unit product via the process, by energy type; total emissions generated, by emission type; and annual quantities for the annual production of the product. On page 2, the amounts of fuel used are shown, by fuel type; as well as the costs of the fuel used, by fuel type; the amounts of pollution generated via the generation of the electricity used in the process; and, finally, certain process parameters.

Add

A new process record can be added to the Process data base by pushing the *Add* button on the general process data input screen and filling in the blanks on the screen. To add information to a field, use the arrow keys or the mouse to highlight the field, and then type in the desired value. Information on re-engineering suggestions for the new process can be put into the data base by pushing the *Re-Engineering Suggestions* button and adding the information in the screen. Push *Exit* to save the input on the screen, close the screen, and exit back to the general process data input screen. (If you decide not to save the information, push *Undo* to cancel it but stay on the screen, or the *Cancel* button to cancel the added data and exit.) When finished with the general process data input screen, use the *Save* button to save the changes to the data base or the *Cancel* button to cancel the added data.

Warning. The data to be filled in on the general process data input screen for base-name abbreviation must be selected from the list of abbreviations already residing in the Base data base. This information is used in the process data base to link a process to a specific base so that base-specific data for process analyses can be retrieved properly. The abbreviations in the data base have been determined to make each one a unique identifier of a specific base.

After the general process data have been added for a new process, data for that process's operation(s) must be added to the Operations data base (a process must have at least one operation). This is done by pushing the *Add* button on the first operation data input screen and filling in the blanks on the screen. To add information to a field, use the arrow keys or the mouse to highlight the field, and then type in the desired value. When finished with the first data input screen, use the *Save* button to save the changes to the data base or the *Cancel* button to cancel the added data. (If the process being added has no operations data already in the Operations data base, only the *Add* button can be pushed, after which action the *Save* button should be pushed, thereby creating a blank operation record ready to be edited.) Access the second data input screen by pushing the *Page 2* button. Push the *Edit* button, and make the desired additions to the data. Use the *Save* button on each input screen to save the changes to the data base or the *Cancel* button to cancel the added data on that screen.

On the second operation data input screen, there is a *Calculate Material and Energy Balances* button. Pushing this button after the data have been entered on both screens for the operation will activate a calculation of the material and energy balances for the operation from the given data. The results can be seen in the middle of the screen. As another aid in evaluating the data and obtaining suggestions for process improvements, there is a process-expert routine that evaluates the process operation data. This routine is invoked by pushing the *Expert Advice* button on either data input screen. Push the *OK* button for more suggestions and to return to the data input screen.

When finished entering the process data for a new operation, access the Emissions data base by pushing the *Emissions* button on the first operation data input screen. The data on HAP emissions that are associated with the process operation (and contained in the Emissions data base) may then be added to the data base by pushing the *Add* button on the HAP data input screen. Pushing the button on the Emissions field activates a scrolling list box with a list of valid HAP species from which one may be selected by a mouse click. Tab the cursor to the quantity field and enter the value for pounds per unit product. Use the *Save* button for each HAP emission input to save the changes to the data base or the *Cancel* button to cancel the added data. (If the operation being added has no emissions data already in the Emissions data base, only the *Add* button can be pushed, after which action the *Save* button should be pushed, thereby creating a blank emission record ready to be edited.) When finished entering the HAP data, push the *Close* button to return to the first operation data input screen.

Edit

The *Edit* procedure is similar to the *Add* procedure except that changes are made to a selected record instead of entering new data. A process record which has been selected can be edited by pushing the *Edit* button and then making the desired changes. To modify the information in a field, use the arrow keys or the mouse to highlight the field, and then type in the desired value. Use the *Save* button to save the changes to the data base or the *Cancel* button to cancel the edits.

An operation record can be edited by pushing the *Edit* button and then making the desired changes. To modify the information in a field, use the arrow keys or the mouse to highlight the field, and then type in the desired value. Use the *Save* button to save the changes to the data base or the *Cancel* button to cancel the edits. When finished with the first data input screen, access the second data input screen by pushing the *Page 2* button. Use the *Edit*, *Save*, and *Cancel* buttons on the second screen in a similar manner as on the first screen to edit and save the edited data on this screen.

Similarly, the HAP emissions data for an operation can be edited by accessing the Emissions data base by pushing the *Emissions* button on the first operation data input screen. Then push the *Edit* button and make the desired changes. To modify the information in a field, use the arrow keys or the mouse to highlight the field, and then type in the desired value. Use the *Save* button to save the changes to the data base or the *Cancel* button to cancel the edits. When finished editing the HAP emissions data, push the *Close* button to return to the first operation data input screen.

Delete

A process (and all of its associated operations and emissions) can be deleted from the Process data base (and Operations and Emissions data bases) by first locating its record on the general process data input screen and then by pushing the *Delete* button. A pop-up question will then appear asking for confirmation to delete the selected record.

A process operation for a given process can be deleted from the Operations data base by first locating its record on the first operation data input screen and then by pushing the *Delete* button. A pop-up question will then appear asking for confirmation to delete the selected record. When an operation record is deleted, the associated HAP emissions records are automatically deleted also. The Operations data base is closed by pushing the *Close* button, to return to the Process data base.

A HAP emission for a given process operation can be deleted from the Emissions data base by first locating its record on the HAP emissions data input screen and then by pushing the *Delete* button. A pop-up question will then appear asking for confirmation to delete the selected record. The Emissions data base is closed by pushing the *Close* button, to return to the Operations data base.

Close

The button bar at the bottom of the first (or only) data input screen for each data base has a *Close* button to close the data base and return to the previous operation level (i.e., close the HAP Emissions data base to return to the Operations data base, or close the Operations data base to return to the Process data base). The Process data base is closed by pushing the *Close* button, to return to the main menu.

Duplicate Process to Create Improved Process

If this operation is selected, a pop-up list appears—*Please Select a Process to Clone*—from which a process may be selected by scrolling through the list and clicking on the desired process. The process list includes all processes in the data base for all services. Each process, which is a unique record in the Process data base, is described in terms of service, base, process category, process name, process ECO, and production line. Existing processes are typically labeled as such in the process ECO column. After the process to be duplicated or cloned has been selected: (1) the base which the new process will be linked to should be edited, if it is to be changed (*using an abbreviation from the Base data base*); (2) a short description of the new process in terms of its ECO should be entered in the field labeled for this purpose; and (3) a production line designation should be entered in the appropriate editing window. After this information, which defines a unique process, has been input and the *OK* button has been pushed, the program will then open the Process data base at the duplicated process record with the general process data displayed in the data input screen. Push the *Edit* button to activate the data editing function.

Note. The three pieces of data that identify a duplicated process (in addition to the duplicated process category and process name, which are retained) must be a unique combination to identify a unique new process. The program will not allow more than one process with the same combination of identifiers to be in the process data base at the same time.

If it is desired to enter data for a completely re-engineered process into the Process data base for comparison with other processes and it is thought to be easier to enter the data from scratch, rather than make small changes in a duplicated process record, the process data may be entered as a new process using the *Add* procedure described above under ***Processes***.

Edit

For making any desired changes in the duplicated process data to create a different, improved process or process variation, the *Edit* procedure described above under ***Processes*** may be used.

However, the program does contain a function to allow you to create an improved or alternative process by substituting an improved technology for an operation in a process already in the data base. This function is invoked by pushing the *Substitute Improved Technology* button in the Operations data base.

A *Select Improved Technology* pop-up will appear. Click on a selected improved technology for that operation. A question will then appear asking for certain information regarding the basis for determining the capacity of the improved technology for substitution in place of the old operation. Provide the information requested, and push the *OK* button to initiate the calculations of new data for the process operation for substitution into the process data base. However, the possible selection of improved technologies depends on what data have been entered into the Improved Technologies data base for this function.

2.3 Process Analyses

You can perform two basic types of process analyses under the *Process Analyses* option of the main menu bar. After first selecting the service, you may choose to view or print the results of an analysis of any single selected process (*Analyze Selected Process*), or the results of a comparison of any two selected processes (*Compare Two Selected Processes*).

Analyze Selected Process

If you selected this operation from the menu, you must then select the base for which a process analysis is desired by scrolling through the *Please Select a Base* pop-up list and clicking on a choice, confirming it with the *OK* button. The subsequent operation involved in selecting a process and doing the process calculations is then limited to processes contained in the data base for the selected base. Next, select a process from the *Please Select a Process* pop-up list by scrolling through the list and clicking on your choice. The process list includes all processes in the data base for the selected base. Each process, which is a unique record in the data base, is described in terms of process category, process name, process ECO, and production line. Existing processes are labeled as such in the process ECO column. After a process has been selected, the type of calculations must be chosen with the appropriate button, either *Analyze Process* or *Hazardous Air Pollutants Totals*. The program will then do the selected calculations and present the results in one or more screens.

Pushing the *Analyze Process* button will activate a series of calculations of the total energy usage in producing a unit product via the process, by energy type; total emissions generated, by emission type; and annual quantities for the annual production of the product. On page 2, the amounts of fuel used are shown, by fuel type; as well as the costs of the fuel used, by fuel type; and, finally, certain process parameters. On page 3 the amounts of pollution generated via the generation of the electricity, and the use of fuel, for the process are shown as well as the associated societal costs.

Pushing the *Hazardous Air Pollutants Totals* button will activate a series of calculations of the totals for the various species of HAP emissions, on the basis of per unit product as well as annual totals for the annual production.

After one set of calculations has been viewed, closing the results screen will return you to the process selection screen from which the other set of calculations may be selected.

Compare Two Selected Processes

The operation to compare two processes is similar to the operation for analyzing one selected process except that two processes must be selected: a "baseline process" and a "comparison process." The process list shown includes all processes in the data base for bases in the selected service, allowing for comparisons between processes at different bases, for example, to determine the most energy-efficient process or the one with the least amount of pollution, to produce the same product. Each selection is accomplished by clicking on a process in the list and then clicking on either the *Set Baseline* or the *Set Comparison* button. After both processes have been selected, the calculations are activated by pushing the *OK* button.

The results are presented in four pages in terms of the differences between the "comparison" and the "baseline" processes. The results of an economic analysis of the comparison process with respect to the baseline process are shown in page 1, but it should be noted that the results of this economic comparison will generally be valid only for related processes, i.e., if the economic data for the comparison process have been determined on the basis of differences with the baseline process. On the next three pages, results similar to the output for a process analysis are shown, but in terms of the differences between the comparison and the baseline processes.

After the calculations have been viewed, closing the results screen (page 1) will deactivate the calculations and return you to the process selection screen. To see additional results, two processes must again be selected.

2.4 Reports

(Potential Future Enhancement)

Individual Process

Process Comparison

Summary of Process Data Base

Analyses of Selected Processes

Comparisons of Selected Processes

2.5 System Administration

You can perform six basic operations under the *System Administration* option. For each possible operation, you may review and edit the data in one of six data bases that contain the data for: (1) the *Improved Technologies* for process operations, (2) the list of *Hazardous Air Pollutants* that currently may be accepted into the HAPs emissions data bases, (3) the *Process Expert Parameters*, (4) the values assumed for *Combustion Efficiencies*, (5) the *ECIP Factors by PADD*, and (6) the values assumed for the *Investment Hurdles*. Each operation is performed in exactly the same way with similar results. The main objective of these operations is to give the user access to these six data bases, either to review the data, or to update them by either adding new records or editing the data in the data base.

Choosing one of the six possible selections results in the opening of the specified data base at the first record with the data displayed in the first data input screen. From this screen, it is possible to perform any desired operation on the data base, using the buttons on the bar along the bottom of the screen. Thus, the record of interest can be found and viewed by either using the *First*, *Previous*, *Next*, or *Last* buttons, or by scrolling and selecting with the *Locate* function. If there is more than one data input screen, the other data input screens for the same record may be viewed at will by pushing the *Page* button or buttons on the menu bar.

Add

A new record can be added to the data base by pushing the *Add* button and filling in the blanks on the data input screen. To add information to a field, use the arrow keys or the mouse to highlight the field, and then type in the desired value. When finished with the data input screen, use the *Save* button to save the changes to the data base or the *Cancel* button to cancel the added data. If there is more than one data input screen, access the additional screens by pushing the appropriate *Page* button. Push the *Edit* button, and make the desired additions to the data. Use the *Save* button on each input screen to save the changes to the data base or the *Cancel* button to cancel the added data on that screen.

Edit

A record can be edited by pushing the *Edit* button and then by making the desired changes. To modify the information in a field, use the arrow keys or the mouse to highlight the field, then type in the desired value. Use the *Save* button to save the changes to the data base or the *Cancel* button to cancel the edits. If there is more than one data input screen, access the additional screens by pushing the appropriate *Page* button. Use the *Edit*, *Save*, and *Cancel* buttons on the second and the third data input screens in a similar manner as on the first screen to edit and save the edited data on each of these screens.

Delete

A record can be deleted from the data base by first locating it on the data input screen and then pushing the *Delete* button. A pop-up question will then appear asking for confirmation to delete the selected record.

Close

The data base is closed and the operation concluded by pushing the *Close* button, to return to the main menu.

Improved Technologies

The Improved Technologies data base contains a number of parameter values for each improved technology. These values are used by the specific routine for each improved technology in conjunction with the data on an existing process to develop estimated process data and costs for an improved process operation. The user may access values of these parameters and change them in the Improved Technologies data base; however, caution is advised in making such changes. One must be aware of how the parameters are used by each specific routine to make reasonable changes.

Any additions of improved technologies to the Improved Technologies data base may require a new specific routine for the new improved technology if the standard routine is not suitable.

Hazardous Air Pollutants

The purpose of this data base is to provide the names of the HAP species that are allowed to be included in the HAP emissions data bases associated with the process operations data base and the improved-technologies data base. Additional HAP species that must be accounted for in air emissions inventories and controlled can be added to this data base as they are specified in new regulations at both the Federal and state levels.

Process Expert Parameters

(Potential Future Enhancement)

The Process Expert data base contains a number of parameter values used by the Process Expert program in conjunction with the data on an existing process for its expert process evaluation. The user can access the values of these parameters and change them in the Process Expert data base, but one must be cautious in making such changes. He must be aware of how the parameters are used by the program to make reasonable changes.

Combustion Efficiencies

(Potential Future Enhancement)

The purpose of this data base is to provide values for the combustion efficiencies of coal, oil, and gas boilers for calculations of the amounts of the fuels required to provide the energy consumed by the industrial processes.

ECIP Factors by PADD

(Potential Future Enhancement)

The purpose of this data base is to provide values for uniform present worth factors and energy discount factors for various fuel types in all five DOE regions for different values of the economic life (10, 15, and 20 years).

Investment Hurdles

(Potential Future Enhancement)

The purpose of this data base is to provide the acceptable values for the investment hurdles of simple payback and savings-to-investment ratio.

2.6 Help

(Potential Future Enhancement)

You can perform three basic operations under the *Help* option. You may browse through the contents of the PEPR Help system, perform a search on the contents of the PEPR Help system, and get development information about the current version of the PEPR system.

Contents

To browse through the contents of the PEPR Help system, select the *Contents* option from under the main *Help* menu bar. This option allows you to get help and/or information on any of the major topics in the PEPR system. When you are finished with this operation, close the window. This is done by clicking on the button in the upper left-hand corner of the window and then pulling down to the *Close* option.

Search

To search the contents of the PEPR Help system, select the *Search* option from under the main *Help* menu bar. This option allows you to search the PEPR Help system using keywords to get help and/or information on any of the major topics in the PEPR system. When you are finished with this operation, close the window by clicking on the button in the upper left-hand corner of the window and then pulling down to the *Close* option.

About PEPR

To get development information on the current version of PEPR, select the *About PEPR* option from under the main *Help* menu bar. When you are finished with this operation, close the window by clicking on the button in the upper left-hand corner of the window and then pulling down to the *Close* option.

2.7 Quit

There is one basic operation which you can perform under the *Quit* option. If you select this option from the main menu bar, you will quit the PEPR system.

Annex A: PEPR Procedures

The PEPR software screening tool has been developed to accommodate the widest variety of types of processes and process data. It has also been developed to address a wide variety of needs in analyzing industrial processes. Because of this flexible general-purpose nature, PEPR can perhaps seem to be difficult to use, especially for a potential user who may not have extensive process-analysis experience. In the main body of the user's manual above—like many computer program manuals—the various program functions are explained as well as the actions resulting from pushing the software "buttons." However, this type of information alone may not be sufficient to tell a potential user how to apply the program to his real problem.

The purpose of this annex is to bridge this gap between the PEPR program user's manual and the needs of the potential user, to describe how to apply PEPR in solving process-analysis problems. This annex contains two sections. After a process model has been conceptualized and process data have been obtained or estimated, the data must be input into the PEPR process data base as a new process so that a PEPR analysis can be performed on it. The procedure for inputting process data into PEPR is described in the first section of this appendix. In addition, the program contains a number of functions designed to aid the user, including a process duplication function for the purpose of creating a new process (or perhaps an improved process) that may be simply a slightly altered version of a process already in the data base. This process duplication procedure is described in the second section.

A.1 Adding a New Process to Process Data Base

One of the most important ways for the user to interact with the PEPR program is to add a new process to the process data base. After gathering data on a process and developing a process model, the user now would like to input the data into PEPR.

The procedure of adding a new process to the process data base is initiated by clicking on the *Process Data* function from the main PEPR menu. The user then must select *Processes* from the submenu. When presented with the process selection list, the user can simply click on the *OK* button to open the Process (general process data) data base at the first record. To add a new process to the data base, the user should push the *Add* button at the bottom of the screen. The blank fields on the screen can then be filled in, by using the mouse or the arrow keys to highlight a field, and by typing in the desired information as described in the main body of the user's manual.

When adding a new process to the Process data base, the critical information to include in the general process data input screen is the

1. Information necessary to designate a unique process, including:
    a. base name abbreviation, which must be taken from the list of abbreviations in the Base data base
    b. process name
    c. production line
    d. process ECO (existing or ECO name)
    f. process category
2. Data required for process analysis and calculations, including:
    a. annual production, units/yr (used to calculate annual quantities of energy and emissions)
    b. production capacity, units/hr (used to calculate electrical demand and to size new technologies).

It is also critical that the operation data on material, energy, and emission flows be on the basis of per unit of product (however the user wishes to define "unit product") because annual quantities of energy usage and pollution generation are calculated by the program by multiplying the operation data (per unit of product) by the annual production (units per year). Adjusting operation data on material, energy, and emission flows that may be on some basis other than per unit of product is the function of the scale factor. For example, data on materials, energy consumption (by type), and emissions (also by type and perhaps also by HAP species) may be available to the user on the basis of: (1) per hour of production, (2) per month, or perhaps (3) annual quantities (per year). The appropriate values of the scale factor, which is a multiplying factor, would be, respectively: (1) 1/(units of product produced per hour), (2) 1/(units of product produced per month), and (3) 1/(units of product produced per year). The scaling function is used after the data on process operations have been entered.

After the general process data have been added for the new process, data for that process's operation(s) must be added to the Operations data base (a process must have at least one operation). The Operations data base is accessed by pushing the *Operations* button at the bottom of the general process data input screen; the first data input screen for the Operations data base is then presented. Data are then entered into the data base via the data input screen as explained in the main body of the user's manual. Since a new process is being entered into the data base, there are no operation records, and no data will show. Initially, only the *Add* button on the first data input screen can be pushed, after which action the *Save* button should be pushed to create a blank operation record for the new process, ready to be edited (i.e., filled in).

The amount and the type of data entered for a particular operation depend on the operation type and the kind of data available. It is not necessary to enter data for every field or even every type of field. The program structure and data bases were developed to be flexible and general-purpose. The program will work with whatever data are provided. Data on material inputs and outputs for an operation, and the temperatures of those materials are entered on the first screen if the operation has material inflows and outflows that are important data for describing the operation. Otherwise, these fields may be left blank; not all process operations have material inputs or outputs that are important and related to the energy consumption or the pollution generation associated with the process.

On the second operation data input screen, which is accessed by pushing the *Page 2* button on the first screen, the energy input and output data are entered, by energy type. Other types of data—on emissions (uncontrolled emissions in lb/unit product, and control factors), equipment description, motor characteristics (size in horsepower and efficiency), wastewater, and waste material—are also entered via this data input screen. The data on material inputs and outputs from the first screen are used to calculate a material balance around the operation with the results shown in the middle of the second screen. The calculated material input and output totals can be compared to see if all of the material has been accounted for, as an aid in evaluating the data.

The data on energy inputs and outputs on the second screen are used to calculate an energy balance around the operation. These results are also shown in the middle of the second screen. The energy input and output totals can then be compared. The theoretical energy requirement is also calculated, as an aid in evaluating the energy efficiency of the process.

Economic data on O&M savings, capital cost, and economic life are entered only for an improved operation (ECO) in an improved process to be evaluated with respect to an existing process as the baseline.

After the data on material and energy flows, emissions, equipment description, etc. have been entered, any data on HAP emissions can be entered by accessing the Emissions data base by pushing the *Emissions* button on the first operations data input screen. If the operation being added has no HAP emissions data already in the Emissions data base, only the *Add* button on the emissions data input screen can be pushed, after which action the *Save* button should be pushed to create a blank emission record ready to be edited (i.e., filled in). The procedure for filling in the emissions data is described in detail in the main body of this user's manual.

After the data on process operations including emissions have all been entered, the Operations data base is closed, and the user returns to the general process data input screen.

If the operations data need to be scaled, the scaling function is used as follows:

1. First, enter the operation data on whatever basis the original data are on.
2. Calculate the appropriate value for the scale factor, and enter it on the general process data input screen.
3. Push the *Scale Operation Data* button on the general process data input screen.

The operation data on materials, energy consumption (by type), and emissions (also by type and perhaps also by HAP species) for all operations will then be multiplied by the scale factor to adjust them to the basis of per unit of product.

A.2 Duplicating and Modifying a Process

To simplify the procedure and lessen the amount of effort involved in inputting data for a process that is very similar to one already in the process data base, the PEPR program contains a function for duplicating ("cloning") a process and making the duplicated data available for editing. Using this function for duplicating a process would benefit the user in the following applications:

1. The user browses the process data base and sees a process at a base that is very similar to one at his base. It would be efficient to input the data for this process and link it to the base with perhaps only a few changes needed in the data. Rather than input all of the data manually from scratch, with ample opportunities for making errors in transcribing the data, the data may be copied via the duplication function and edited appropriately to develop a similar process linked to the base, or perhaps another production line, etc.
2. The user wishes to input data for an improved process related to one already in the data base, and analyze the alternate process, which incorporates one or more ECOs, compared to the existing process in the data base as the baseline. The improved process may have altered only one out of a number of operations. Rather than input all of the data manually from scratch, with the resultant opportunities for errors in transcribing the data, the data may be copied via the duplication function and changed only for the improved operation or operations to develop the improved process ready for comparison with the existing process.

To activate the process duplication function, the user first must select the *Process Data* function from the main PEPR menu. He then must select *Duplicate Process to Create Improved Process* from the submenu.

When the duplicate function has been selected, the user is then given the opportunity to choose the process to be duplicated by being presented with a scroll list of processes entitled *Please Select a Process to Clone*. The user then scrolls through the list of processes, which is organized by service, base (abbreviation), process category, process name, process ECO, and production line; and clicks on his selection.

The program duplicates three critical pieces of data that identify a unique process in the data base: base, process ECO, and production line; and inserts them into three windows for editing. One of these three pieces of data must be changed (to define a new unique process) or else the program will cancel the operation (the data base will not accept two processes with the same critical data; each process in the data base must be unique). To edit the data in any one of these windows, simply click on a window to select it, and insert new data in the usual way. When finished editing the critical data, the user must then click on the *OK* button. The program checks the critical data against the processes already in the data base to make sure that the data will identify a new unique process.

If the identifying data for the new process are unique, the program duplicates all of the other data for the selected duplicated process (with the exception of the reengineering suggestions) and puts them into the data base for the new unique process. The Process (general process data) data base is then opened at the new process record, and the user has the opportunity to edit or change the new process data in the usual way. The user may change the data in individual fields in any of the three data bases containing process data—general process data, operation data, and HAP emissions data. The operation data may be scaled with a scale factor. He can add new operations and delete old ones, add economic data for improved operations, and add data for new HAP emissions, etc. The edited data then comprise the process data for a new unique process in the data base.

Annex B: Values of PEPR Parameters

The PEPR program contains a number of parameters that are used for certain calculations in its analyses. Some of these parameters are basic parameters involved in standard procedures and are not subject to change by the user; other parameters can be changed by the user, perhaps as better data becomes available. The user should be aware of these parameters and their values to better understand PEPR analyses.

B.1 Compressed-Air and Steam Supply Loss Factors

In the Base data base, there are two fields for each base record (on page 2) for loss factors associated with central energy supply systems, one factor for a centralized compressed-air supply and distribution system, and the other for a centralized steam supply and distribution system. Each loss factor is the percent of the energy supply lost in the distribution system between the central generation plant and the point of use of the compressed air or the steam. These loss factors are used to back-calculate the amount of energy saved at the central generation plant as the result of saving each Btu in energy usage at the process. Ultimately, the amount of primary fuel saved is then calculated, including the conversion efficiency of generating the distributed energy if one is applicable.

Thus, with each Btu saved at the process or point of use, the loss associated with getting that Btu to the process is also saved. In a PEPR analysis, the amount of energy saved at the process is estimated, and then the amount of energy saved at the central plant is calculated, from the following:

$$\text{Amount of energy saved at central plant} = \frac{\text{Amount of energy saved at the process}}{(1 - \%\text{loss}/100)} \qquad \text{[Eq A1]}$$

Depending on how well the compressed-air or steam distribution systems are maintained, these losses—caused by, for example, leaky fittings in compressed-air systems or malfunctioning steam traps in steam systems—can be significant. As a reasonable approximation for these loss factors, 25 percent has been loaded initially into the Base data base for both the steam loss factor and the compressed-air loss factor for each base. These values may be changed for individual bases as better data may become available.

The application of these loss factors accounts for the difference in the energy usage results of "Total (Steam or Compressed Air) Usage," and "Total (Steam or Compressed Air) Usage including System Loss." The latter figure is the one used in calculating the value of the fuel saved in the economic analysis of an ECO.

B.2 Boiler Combustion Efficiencies

In the case of steam, once the amount of energy saved at the central plant has been estimated, then the amount of primary fuel saved at the boiler is calculated by applying an estimated boiler combustion efficiency for generating steam from the primary fuel. This combustion efficiency is a function of the primary fuel. The values used in PEPR were taken from the REEP program (Table A1).

Table A1. Combustion efficiency as a function of primary fuel.

Fuel	Combustion Efficiency, %
Coal	60
Oil	65
Gas	70

These values are incorporated into the program as the "Combeffi" data base.

B.3 Economic Parameters

B.3.1 Economic Life

The economic life of an ECO is an important parameter. It determines how many years of savings should be considered in the economic analysis. In the economic analysis in PEPR, which was taken from the REEP program, the economic life is used in a lookup table to find appropriate values of cumulative discount factors (life cycle uniform present worth factors), as a function of region, fuel type, etc. The only values of economic life included in the table are 10, 15, and 20 years; therefore, these are the only values of economic life allowed in PEPR.

Although most improved processes put into the PEPR data base will probably have only one ECO, for ease of analysis, it is possible to define a process having more than one ECO. The question then becomes one of dealing with several different economic lives for the different ECOs that the improved process may include. The economic analysis in PEPR involves an improved process taken as a whole with only one economic life allowed in the calculations. The question becomes how to arrive at a suitable value for the economic life, and hence the discount factors. To handle this possible situation, the program looks for the highest value of the economic life, and adjusts the capital investments for ECOs with smaller lives.

In a simplified treatment of the problem, an adjusted total capital cost is calculated from the following, so that the ECOs all have the same life:

$$\text{Total Capital Cost} = \sum_{\text{All Operations (ECOs)}} \frac{\text{Capital Cost}_i \times \text{Econlife}_{max}}{\text{Econlife}_i} \qquad \text{[Eq A2]}$$

B.3.2 Discount Factors

A lookup table of values of cumulative discount factors (life cycle uniform present worth factors), as a function of region, fuel type, etc., is included in PEPR for the economic analysis. This table, called the "Ecipdata" data base, is taken from REEP, and is shown in Table A2.

B.3.3 Economic Filters

Hurdle values of simple payback and savings-to-investment ratio are used to flag investments that meet minimum criteria of acceptability. These parameters are contained in the "Filtdata" data base. The minimum acceptable value of savings-to-investment ratio is 1.25, and the maximum acceptable value of simple payback is 10 years.

Table A2. Ecipdata Database

Period	10	15	20
Life Cycle Uniform Present Worth Factor	**8.49**	**11.85**	**14.74**
Region 1 Discount Factors:			
Electricity	8.69	12.25	15.41
Distillate	9.20	13.44	17.35
Residuals	9.89	14.70	19.35
Natural Gas	9.67	14.34	18.65
Coal	9.20	13.32	17.20
Region 2 Discount Factors:			
Electricity	8.47	11.93	14.92
Distillate	9.22	13.49	17.44
Residuals	10.01	14.96	19.75
Natural Gas	9.75	14.53	18.93
Coal	9.02	13.00	16.72
Region 3 Discount Factors:			
Electricity	8.77	12.43	15.61
Distillate	9.26	13.56	17.56
Residuals	10.08	15.09	19.97
Natural Gas	10.39	15.86	20.96
Coal	9.39	13.61	17.58
Region 4 Discount Factors:			
Electricity	8.82	12.49	15.64
Distillate	9.23	13.51	17.47
Residuals	10.06	15.06	19.91
Natural Gas	9.86	14.73	19.21
Coal	9.11	13.10	16.83
Region 5 Discount Factors:			
Electricity	8.67	12.26	15.37
Distillate	9.23	13.52	17.48
Residuals	10.02	14.96	19.75
Natural Gas	10.12	15.26	20.03
Coal	9.22	13.31	17.13

Annex C: HAPS Data Base

In the PEPR program, there is a data base of HAP species names called the "HAPs" data base. The purpose of this data base (validation table) is to provide the names of the HAP species to HAP emissions data bases (there are 2), and make it easy to update the list of potential HAP species and keep the structures of the HAP emissions data bases consistent whenever additional species might be added in the future. The current list of 48 HAP species in the HAPs data base is shown in Table A3.

The HAPs data base may be viewed, browsed, edited, and added to just like any other data base. This function, which is explained in the main body of the manual, is provided under "System Administration" on the main menu bar.

Table A3. HAP species in HAPs data base.

HAP Species
acetaldehyde
acrolein
antimony compounds
arsenic
barium compounds
beryllium
benzene
1,3-butadiene
cadmium
carbon tetrachloride
chlorobenzene
chloroform
chromium compounds
cumene
cyanide compounds
1,4-dichlorobenzene
1,1-dichloroethylene
ethylbenzene
ethylene dichloride
ethylene glycol

HAP Species
formaldehyde
glycol ethers
hexane
lead compounds
manganese compounds
mercury compounds
methanol
methyl ethyl ketone
methyl isobutyl ketone
methylene chloride
naphthalene
nickel compounds
perchloroethylene
POM
selenium compounds
silver
styrene
tetrachloroethylene
toluene
toluene-2,4-diisocyanate
1,1,1-trichloroethane
trichloroethylene
vinyl acetate
vinyl chloride
xylene
m-xylene
o-xylene
p-xylene

Annex D: Process-Expert Routine

Each process in the process data base is analyzed automatically with certain calculations: material and energy balances, and, if the data are appropriate and sufficiently complete (temperatures of materials in and out, etc.), theoretical energy requirements for individual operations. The Operations data base has fields open for the results of these calculations. The data and this quantitative information can then be analyzed by a process-expert routine of expert suggestions that examines the operation data and poses questions intended to stimulate the user's thinking regarding potential process improvements.

This process-expert routine generates comments and quantitative estimates, where appropriate, for savings in energy consumption and/or emissions based on a quick analysis and rules of thumb regarding potential process improvements. As experience is gained by various users in the use of the program, this process-expert routine and its associated data base, which contains parameter descriptions and values, can be updated and added to. In structure the routine is comprised of various parts that are concerned with the analysis of specific types of process data (i.e., material flows, temperatures of process and energy supply, theoretical energy requirement, pressures, emission control factors, motor efficiencies, etc.) for each operation. The comments and the estimates of energy savings are made available as output on a screen from the analysis procedure. The routine should be changed and updated only by a user who is knowledgeable in FoxPro programming.

The routine is invoked by pushing a button labeled *Expert Advice* on either of the two operations data input screens.

Table A4 describes the structure of the process-expert ("Exp") data base. It is rather simple, containing only parameter descriptions and parameter values. The parameters are used in specific types of calculations and evaluations done by the process-expert routine and are likely to be expanded or changed over time as the routine evolves.

Table A4. Process-Expert Database

Record No.	Parameter Description C 50	Parameter Value N 12.5
1	Efficiency of efficient drying process	0.30
2	Up-to-date control factor (%) for VOCs	90
3	Up-to-date control factor (%) for HAPs	85
4	Up-to-date control factor (%) for TSP	96
5	Up-to-date control factor (%) for PM_{10}	65
6	Up-to-date control factor (%) for SO_x	97
7	Up-to-date control factor (%) for NO_x	60
8	Up-to-date control factor (%) for CO	95
9	Increment of press. reduct. (psi) for comp. air	1
10	% energy saved for incremental press. reduct. for comp. air	0.5
11	Increment of press. reduct. (psi) for steam supply	10
12	% energy saved for incremental press. reduct. for steam	1
13	standard efficiency (%) for 1-hp motor	76.1
14	high efficiency (%) for 1-hp motor	83.0
15	standard efficiency (%) for 10-hp motor	86.9
16	high efficiency (%) for 10-hp motor	91.4
17	standard efficiency (%) for 100-hp motor	92.3
18	high efficiency (%) for 100-hp motor	95.5
19	standard efficiency (%) for 500-hp motor	94.0
20	high efficiency (%) for 500-hp motor	95.1

Listing of PEPR Process-Expert Routine

A description of the the initial version of the process-expert routine follows.

This routine is called upon to analyze the data for a process operation. It is developed in sections, each dealing with a different type of process data. Sections are easily modified, or new ones added. Parameter values which are included in the process-expert database (and thus can be updated easily via the database) are used in the routine. In the description of the routine below, parameter value 'n' from the process-expert database = **ParVal'n'**; data item from operation database = **DataName** (in bold face).

Theoretical Energy Requirement:

If **OperationName** contains the string 'dry' and **TheoreticalEnergyRequirement/TotalEnergyIn** < **ParVal'1'**, then print the comment 'Drying process appears to be inefficient. Consider a more efficient drying process. Is it possible to recover any of the thermal energy in the exhaust from the dryer? Estimate of potential energy savings from a more efficient drying process is (**TotalEnergyIn**)-(**TheoreticalEnergy-Requirement/ParVal'1'**)'.

Analysis of Emission Control Factors:

If any of the **ControlFactor** (%) data > 0 for any of the 7 emissions, do the following: compare the data with that of up-to-date control equipment for the emission in question.

(1) If the given **ControlFactorforVOCs** < **ParVal'2'**, then print the comment 'The given Control Factor for VOCs is only **ControlFactorforVOCs** %. Up-to-date emission control equipment for this pollutant has a Control Factor of **ParVal'2'** %. Estimate of potential reduction in VOC emissions through improved control is (**VOCs**)(**ParVal'2'-ControlFactorforVOCs**)/100'.

(2) If the given **ControlFactorforHAPs** < **ParVal'3'**, then print the comment 'The given Control Factor for HAPs is only **ControlFactorforHAPs** %. Up-to-date emission control equipment for this pollutant has a Control Factor of **ParVal'3'** %. Estimate of potential reduction in HAP emissions through improved control is (**HAPs**)(**ParVal'3'-ControlFactorforHAPs**)/100'.

(3) If the given **ControlFactorforTSP** < **ParVal'4'**, then print the comment 'The given Control Factor for TSP is only **ControlFactorforTSP** %. Up-to-date emission control equipment for this pollutant has a Control Factor of **ParVal'4'** %. Estimate of potential reduction in TSP emissions through improved control is (**TSP**)(**ParVal'4'-ControlFactorforTSP**)/100'.

(4) If the given **ControlFactorforPM**$_{10}$ < **ParVal'5'**, then print the comment 'The given Control Factor for PM_{10} is only **ControlFactorforPM**$_{10}$ %. Up-to-date emission control equipment for this pollutant has a Control Factor of **ParVal'5'** %. Estimate of potential reduction in PM_{10} emissions through improved control is (**PM**$_{10}$)(**ParVal'5'-ControlFactorforPM**$_{10}$)/100'.

(5) If the given **ControlFactorforSO**$_x$ < **ParVal'6'**, then print the comment 'The given Control Factor for SO_x is only **ControlFactorforSO**$_x$ %. Up-to-date emission control equipment for this pollutant has a Control Factor of **ParVal'6'** %. Estimate of potential reduction in SO_x emissions through improved control is (**SO**$_x$)(**ParVal'6'-ControlFactorforSO**$_x$)/100'.

(6) If the given **ControlFactorforNO**$_x$ < **ParVal'7'**, then print the comment 'The given Control Factor for NO_x is only **ControlFactorforNO**$_x$ %. Up-to-date emission control equipment for this pollutant has a Control Factor of **ParVal'7'** %. Estimate of potential reduction in NO_x emissions through improved control is (**NO**$_x$)(**ParVal'7'-ControlFactorforNO**$_x$)/100'.

(7) If the given **ControlFactorforCO** < **ParVal'8'**, then print the comment 'The given Control Factor for CO is only **ControlFactorforCO** %. Up-to-date emission control equipment for this pollutant has a Control Factor of **ParVal'8'** %. Estimate of potential reduction in CO emissions through improved control is (**CO**)(**ParVal'8'-ControlFactorforCO**)/100'.

Analysis of Wastewater:

If the data on **Wastewater** > 0, print the comment 'Can the production of this wastewater be minimized or eliminated, perhaps by changing the conditions of the process operation, or by using a dry filter or some other means to collect the waste material now being ejected from the process via scrubbing or dissolution in water? Can the waste material be collected and recycled to be reused?'

Analysis of Waste Material:

If the data on **WasteMaterial** > 0, print the comment 'Can the production of this waste material be minimized, perhaps by changing the conditions of the process operation? Can it be collected and recycled to be reused?'

Analysis of Heat Recovery Opportunities:

If the **SteamInput** > 0, print the comment 'Since steam is being used to supply energy to this process, is the condensate being recovered?'

If the **HotAirInput** > 0, print the comment 'Since hot air is being used to supply energy to this process, is it possible to recover some heat from the exhausted hot air?'

If the **HotWaterInput** > 0, print the comment 'Since hot water is being used to supply energy to this process, is it possible to recover some heat from the exhausted hot water?'

Analysis of Compressed Air:

If the **CompressedAirInput** > 0, print the comment 'Can the pressure of the compressed air used in the process be reduced? A pressure reduction of **ParVal'9'** psi will save **ParVal'10'**% of the energy consumed in generating the compressed air.'

Analysis of Steam:

If the **SteamInput** > 0, print the comment 'Can the pressure of the steam supplied to the process be reduced? A pressure reduction of **ParVal'11'** psi will save **ParVal'12'**% of the energy required to generate the steam needed.'

Analysis of Motor Efficiency:

For any given data on **MotorSize**, the energy efficiency of a high-efficiency motor of the same size for comparison ('HighEfficiency')is calculated via the following:

If **MotorSize** (hp) ≤ 1, 'HighEfficiency' = **ParVal'14'**%.
If 1 < **MotorSize** (hp) ≤ 10, 'HighEfficiency' = **ParVal'14'+(ParVal'16'-ParVal'14')*(MotorSize**-1)/9 %.
If 10 < **MotorSize** (hp) ≤ 100, 'HighEfficiency' = **ParVal'16'+(ParVal'18'-ParVal'16')*(MotorSize**-10)/90 %.
If 100 < **MotorSize** (hp) ≤ 500, 'HighEfficiency' = **ParVal'18'+(ParVal'20'-ParVal'18')*(MotorSize**-100)/400 %.
If **MotorSize** (hp) > 500, 'HighEfficiency' = **ParVal'20'**%.

If there is process data given for **MotorEfficiency** as well as **MotorSize** (hp), compare the given data with the efficiency of an energy-efficient motor of the same size ('HighEfficiency' calculated above):

(1) If the given **MotorEfficiency** < 'HighEfficiency', print the comment 'An energy-efficient motor of the same size would have an efficiency of ('HighEfficiency') % compared to **MotorEfficiency**, thus saving (1 - **MotorEfficiency**/'HighEfficiency') % in energy consumption. Estimated energy saving in Btu/unit product by substituting an energy-efficient motor for present motor in this operation is (print result of calculation below).':

2,545,10***MotorSize***(1/**MotorEfficiency** - 1/'HighEfficiency')/**UNITS_PR_HR**

(2) If the given **MotorEfficiency** ≥ 'HighEfficiency', print the comment 'The given motor appears to be energy efficient; no saving in energy consumption appears to be possible by substituting for it.

If no process data is given for motor efficiency, only for **MotorSize** (hp), compare a default value of the efficiency of an old standard motor ('StdEfficiency' calculated below) with that of an energy-efficient motor of the same size ('HighEfficiency' calculated above):

If **MotorSize** (hp) ≤ 1, 'StdEfficiency' = **ParVal'13'**%.
If 1 < **MotorSize** (hp) ≤ 10, 'StdEfficiency' = **ParVal'13'**+(**ParVal'15'**-**ParVal'13'**)*(**MotorSize**-1)/9 %.
If 10 < **MotorSize** (hp) ≤ 100, 'StdEfficiency' = **ParVal'15'**+(**ParVal'17'**-**ParVal'15'**)*(**MotorSize**-10)/90 %.
If 100 < **MotorSize** (hp) ≤ 500, 'StdEfficiency' = **ParVal'17'**+(**ParVal'19'**-**ParVal'17'**)*(**MotorSize**-100)/400 %.
If **MotorSize** (hp) > 500, 'StdEfficiency' = **ParVal'19'**%.

Print the comment 'What is the motor efficiency? No data is given. The efficiency of an old standard motor of this size, (**MotorSize**) hp, is approximately ('StdEfficiency') %; an energy-efficient motor should have an efficiency of at least ('HighEfficiency') %. Estimated energy saving in Btu/unit product by substituting an energy-efficient motor for present motor in this operation is (print result of calculation below).':

2,545,10***MotorSize***(1/'StdEfficiency' - 1/'HighEfficiency')/**UNITS_PR_HR**

Annex E: Improved-Technology Routines

E.1 Description

The PEPR program can help the user develop and analyze an improved process by providing improved technologies to substitute for one or more operations of an existing process. The improved process is generated by the software on the basis of user-selected technologies from a data base of improved technologies for specific operation types.

Each substituted process operation is generated by using a data base/routine specific for a selected improved technology to develop rough figures for improved energy consumption and pollution generation scaled, for example, to one of the input materials, or to some other aspect of the existing operation. It is possible for the improved technology to have a different material balance from that of the existing operation. A perfect substitution of the new technology would therefore involve a recalculation of the material balance for the entire process, a procedure at the present time thought to be unnecessarily complex for the objective of developing a PEPR screening tool; PEPR is not developed to have the capabilities of a general-purpose process simulator.

The substitution of an improved technology for an operation in an existing process is invoked by pushing the button labeled *Substitute Improved Technology* on the data input screen in the operations data base. Details on the use of this function are contained in the main body of this manual.

E.2 Improved-Technology Data Base

The improved-technology ("Tech") data base used for selecting improved technologies is organized on the basis of certain types of information on each improved technology (one technology per record)—general operation type (e.g., drying, conveying, spray painting, etc.), specific improved technology (e.g., infra-red drying, microwave drying, water-based latex paint, powder paint, etc.), and the process which was the source and the basis for the improved technology. The Tech data base (Table A5) also contains fields in each improved-technology record for parameter values that may be used by the routine for each improved technology for process and cost calculations. A field is also included for each parameter containing its description. The organization of the improved-technology data base and the type of information contained in it thus resemble the data base of Energy Conservation Opportunities (ECOs) in the REEP program.

Table A5. Structure of improved-technology ("tech") data base.

Field	Data	Field Name	Type	Width
One record per improved technology				
1	General Operation Type (e.g., drying, conveying, spray painting, etc.)	GEN_OP_TYP	C	50
2	Specific Improved Technology (e.g., infra-red drying, microwave drying, water-based latex paint, etc.)	SPEC_TECH	C	50
3	Process/Product Source of Improved Technology	SOURCE	C	50
4	Routine (Program) Name	PRG_NAME	C	8 (for future use)
5	Name of Basis for Baseline Capacity for Capital Cost (e.g., if a material flow is the basis, this would be the name of the material, etc.)	BASIS_NAME	C	15
6	Category of Capacity Basis (MF = material flow, EM = emissions flow, EN = energy flow, ES = equipment size, MS = motor size, and CN = constant, everything else)	CAT_CP_BAS	C	2
7	Production Capacity for Baseline Capital Cost (e.g., a material flow rate or some other measure of production capacity for the baseline system)	BASLN_CAP	N	10.2
8	Dimensional Units for Production Capacity for Baseline Capital Cost (preferably lb/hr for a material or an emissions flow, and Btu/hr for an energy flow, and hp for motor size)	UNITS	C	10
9	Baseline Capital Cost, $	BASLN_COST	N	8
10	Capital Cost Capacity Exponent	CST_CP_EXP	N	5.3
11	Baseline Annual O&M Cost Saving,			
	$/yr	BAS_OM_SAV	N	6
12	Economic Life, yr	ECON_LIFE	N	2
13	Methodology Flag (0 for make individual changes in duplicated old process data, 1 for direct substitution of all new process data, 2 for using individual multiplicative factors to generate the new process data)	METH_FLAG	C	1
14.-23	Parameter Descriptions and Values, 5 combinations (for future use)			

Field	Data	Field Name	Type	Width
14	Parameter Description	PAR_DESC1	C	50
15	Parameter Value	PAR_VALUE1	N	12.5
16	Parameter Description	PAR_DESC2	C	50
17	Parameter Value	PAR_VALUE2	N	12.5
18	Parameter Description	PAR_DESC3	C	50
19	Parameter Value	PAR_VALUE3	N	12.5
20	Parameter Description	PAR_DESC4	C	50
21	Parameter Value	PAR_VALUE4	N	12.5
22	Parameter Description	PAR_DESC5	C	50
23	Parameter Value	PAR_VALUE5	N	12.5
(Note: From this point on, the database has the same fields as the Oper.dbf, with the data to be used for generating new operation data for substitution into the Oper.dbf after the data have been scaled, etc. to the proper basis.)				

The data in the Tech data base for the most part resemble the data in the process operations (Oper) data base, and just like the operations data base, there is a HAP emissions ("Itemmis") data base linked to the Tech data base which contains HAP emissions data for the improved technologies. The data in the Itemmis data base are used by the routine to generate substitute HAP emissions data to be put into the Emmis data base for the improved operation in the new improved process.

E.3 Improved-Technology Routine

The function of the improved-technology routine is to generate new process data for the improved operation. This procedure may involve interactions with the user in the form of questions for pertinent information. As one example of such an interaction, the question may be asked about which material flow the capacity and the cost of the equipment should be based on. The improved-operation data generated by the routine from the baseline data in Tech (by adjusting material, energy, and emissions flows, and capital cost for capacity, for example) are put into the process operation data base for the improved process in place of the corresponding operation for the existing process, which initially should be duplicated in the data base for subsequent modification. The new improved process with its improved operations can then be analyzed and compared with its baseline existing process.

The routine also includes methodology for generating necessary cost information for the improved technology to be used as part of the input for the economic analysis of the improved process vis-a-vis the existing process.

Some improved technologies may each require its own specific routine, but many will be able to use a "standard" routine, which is programmed into PEPR and is described below. The routine appropriate for a particular improved technology would be invoked every time that technology is chosen to replace an operation in an existing process. The purpose of the routine is to generate the set of new operation data that replaces the old set of operation data in the operation data base for the baseline existing process, and to generate the economic data on the improved technology, which is scaled to the proper size for substitution into the existing process.

The routine involves asking the user some questions to: (1) determine the right type of data for scaling purposes, and (2) obtain some specific data that may be necessary for a particular technology. When the right type of data has been determined and the specific data needed have been obtained, a new-capacity ratio ("newcaprat") is calculated that is used for data-scaling purposes and estimating operation and maintenance (O&M) savings and capital cost.

The routine also involves using a specific procedure for generating the new process data for the improved operation with calculations on the old operation data. Three types of procedures are included in this initial version of the standard improved-technology routine, as directed by the methodology flag in the data base (METH_FLAG): (1) make selected individual changes in duplicated old operation data (METH_FLAG = 0), (2) direct and complete substitution of the improved-technology data for the existing data (METH_FLAG = 1), perhaps scaled to the proper production capacity, or (3) using multiplicative factors to multiply the old data to generate the new data (METH_FLAG = 2). Other general procedures may easily be defined and included in an updated standard routine as experience is gained with the program.

A Standard Routine for Improved Technologies

The following stepped process describes a "standard" routine for improved technologies:

A. <u>Establishment of Basis for Baseline Capacity</u>

Check CAT_CP_BAS. (CAT_CP_BAS could be MF (material flow), EM (emissions flow), EN (energy flow), ES (equipment size), MS (motor size), or CN (constant, everything else).)

If MF: Ask question: 'Basis for baseline capacity in database is a material flow, BASIS_NAME [i.e., print this variable information from database], at BASLN_CAP UNITS. What material flow in the data for the operation does this correspond to?' From the data for the operation, show list of material flows in and out, for user to make selection. With the quantity data on the selected material flow for the operation obtained from the operation database, do the calculation:

newcaprat = (QUAN_???*UNIT_PR_HR[units/hr])/BASLN_CAP

Go to next section (B).

If EM: Ask question: 'Basis for baseline capacity in database is an emissions flow, BASIS_NAME, at BASLN_CAP UNITS. What emissions flow in the data for the operation does this correspond to?' From the data for the operation, show list of emissions flows, for user to make selection. With the quantity data on the selected emissions flow for the operation obtained from the operation database, do the calculation:

newcaprat = ([emissions-flow in lb/unit]*UNIT_PR_HR[units/hr])/BASLN_CAP
Go to next section (B).

If EN: Ask question: 'Basis for baseline capacity in database is an energy flow, BASIS_NAME, at BASLN_CAP UNITS. What energy flow in the data for the operation does this correspond to?' From the data for the operation, show list of energy flows, for user to make selection. With the quantity data on the selected energy flow for the operation obtained from the operation database, do the calculation:

newcaprat = ([energy-flow in Btu/unit]*UNIT_PR_HR[units/hr])/BASLN_CAP
Go to next section (B).

If ES: Ask question: 'Basis for baseline capacity in database is an equipment size, BASIS_NAME, at BASLN_CAP UNITS. What is the corresponding equipment size for the data for the operation?' From the user's answer, do the calculation:

newcaprat = (user input on equipment size)/BASLN_CAP
Go to next section (B).

If MS: Ask question: 'Basis for baseline capacity in database is a motor size, BASIS_NAME, at BASLN_CAP UNITS. With the data on the motor size for the operation obtained from the operation database, do the calculation:

newcaprat = MOTOR_SIZ/BASLN_CAP
Go to next section (B).

If CN: Ask question: 'Basis for baseline capacity in database is a constant, which means that the baseline capital cost, BASLN_COST, does not appear to vary with production capacity. No scaling of baseline capacity or capital cost is indicated.'

newcaprat = 1
Go to next section (B).

B. Estimation of O&M Cost Savings and Capital Cost Based on New Capacity Ratio

O&M Cost Savings (assumed to be directly proportional to newcaprat):

omcostsav = BAS_OM_SAV*newcaprat

(Store the result 'omcostsav' in OM_SAVINGS for the improved operation for the improved process in the operation database.)

Scaled Capital Cost:

newcapcost = BASLN_COST*(newcaprat^CST_CP_EXP)

(Store the result 'newcapcost' in CAPCOST for the improved operation for the improved process in the operation database.)

Economic Life:

Store the value for ECON_LIFE (item 12 above) in ECONLIFE for the improved operation for the improved process in the operation database.

Go to next section (C).

C. Estimation of Process Data for Improved Operation

Check METH_FLAG. (METH_FLAG could be 0 (make selected individual changes in duplicated old process data), 1 (direct and complete substitution of the improved-technology data for the existing data, perhaps scaled to the proper production capacity), or 2 (use individual multiplicative factors to multiply the old data to generate the new data).)

If 0: Duplicate all information and data from the old operation in the existing process into the operation database for the improved operation in the Level-2 improved process linked to the selected existing process. Scan the fields from 24. to 146. in the improved-technology database; for any which are not blank, abstract the information, and substitute it for the old information for that field which was initially duplicated into the database for the new operation.

If 1: New values for all material flows, emissions flows, and energy flows for the improved operation (and put into the operations database to replace the old set of operation data in the improved process) are the values for these items abstracted from the improved-technology database multiplied by 'newcaprat'. Description, comment, names, temperatures, pressures, process conditions, properties of materials, and emissions control factors are abstracted from the improved-technology database as is without any change and put into the corresponding field in the operation database for the improved operation. (Note: This procedure is exactly analogous to the procedure for scaling process data for a different basis.)

If 2: Duplicate all information and data from the old operation in the existing process into the operation database for the improved operation in the improved process. Scan the fields from 24. to 146. in the improved-technology database. For any data fields which are not typically scaled (description, comment, names, temperatures, pressures, process conditions, properties of materials, and emissions control factors) and are not blank, abstract the information, and substitute it for the old information for the corresponding field which was initially duplicated into the database for the new operation. For any numeric fields which are typically scaled (all material flows, emissions flows, and energy flows) and are not blank, abstract the data, which will be assumed to be a percentage; calculate new data (see below); and substitute the result for the old information in that field which was initially duplicated into the database for the new operation.

new value = (value for existing operation)*(data from improved-technology database)/100

(end of 'standard' improved-technology routine)

Annex F: Base Name Abbreviations

The following list contains base names and their abbreviations as they have been defined for the PEPR Base data base.

Service	Base_name	Faci_abr
ARMY	ABERDEEN P.G.	ABDPG
ARMY	ANNISTON DPT	ANAD
ARMY	BADGER AAP	BAAP
ARMY	CORPUS CHRISTI DPT	CCAD
ARMY	DETROIT ARS TANK PL	DATP
ARMY	DETROIT ARSENAL	DARS
ARMY	DUGWAY PG	DUGPG
ARMY	FT MONMOUTH	FTMM
ARMY	HAWTHORNE AAP	HWAAP
ARMY	HOLSTON AAP	HSAAP
ARMY	INDIANA AAP	INAAP
ARMY	IOWA AAP	IWAAP
ARMY	JEFFERSON PG	JEFPG
ARMY	KANSAS AAP	KAAP
ARMY	LAKE CITY AAP	LCAAP
ARMY	LETTERKENNY ARMY DPT	LKAD
ARMY	LEXINGTON BLUE GRASS	LBGAD
ARMY	LIMA TANK PLANT	LTP
ARMY	LONE STAR AAP	LSAAP
ARMY	LONGHORN AAP	LHAAP
ARMY	LOUISIANNA AAP	LAAAP
ARMY	MCALESTER AAP	MCAAP
ARMY	MILAN AAP	MLAAP
ARMY	MISSISSIPPI AAP	MSAAP
ARMY	NATICK DEV CEN	NDC
ARMY	NEWPORT AAP	NAAP
ARMY	PICATINNY ARS	PARS
ARMY	PINE BLUFF ARS	PBARS
ARMY	PUEBLO DPT	PAD
ARMY	RADFORD AAP	RFAAP
ARMY	RAVENNA AAP	RVAAP
ARMY	RED RIVER DPT	RRAD
ARMY	REDSTONE ARS	RDARS
ARMY	ROCK I. ARS	RIARS
ARMY	SACRAMENTO ARMY DPT	SAAD
ARMY	SAVANNA DEPOT ACTIVI	SDA
ARMY	SCRANTON AAP	SAAP
ARMY	SENECA ARMY DEPOT	SENAD
ARMY	SIERRA ARMY DEPOT	SRRAD

Service	Base_name	Faci_abr
ARMY	SUNFLOWER AAP	SFAAP
ARMY	TOBYHANNA AD	THAD
ARMY	TOOELE DPT	TAD
ARMY	TWIN CITIES AAP	TCAAP
ARMY	UMATILLA ARMY DPT	UAD
ARMY	VINT HILL FARMS STAT	VHFS
ARMY	VOLUNTEER AAP	VAAP
ARMY	WATERVLIET ARS	WARS
ARMY	WHITE SANDS M.R.	WSMR
ARMY	YUMA PG	YPG
ARMY	FT A P HILL	FTAPH
ARMY	FT BRAGG	FTBRG
ARMY	FT BUCHANAN	FTBUC
ARMY	FT CAMPBELL	FTCAM
ARMY	FT CARSON	FTCAR
ARMY	FT DEVENS	FTDEV
ARMY	FT DRUM	FTDRM
ARMY	FT HOOD	FTHOD
ARMY	FT HUNTER LIGGET	FTHL
ARMY	FT INDIANTOWN GAP	FTITG
ARMY	FT IRWIN	FTIRW
ARMY	FT LEWIS	FTLEW
ARMY	FT MCCOY	FTMCC
ARMY	FT McPHERSON	FTMCP
ARMY	FT MEADE	FTMDE
ARMY	FT ORD	FTORD
ARMY	FT PICKETT	FTPIC
ARMY	FT POLK	FTPOL
ARMY	FT RILEY	FTRIL
ARMY	FT SAM HOUSTON	FTSH
ARMY	FT SHERIDAN	FTSHR
ARMY	FT STEWART	FTSTW
ARMY	HUNTER AAF	HAAF
ARMY	KELLY SUP FAC	KSF
ARMY	PRESIDIO OF MONTEREY	POM
ARMY	PRESIDIO OF SAN FRAN	POSF
ARMY	FITZSIMMONS AMC	FAMC
ARMY	FT DETRICK	FTDET
ARMY	WALTER REED AMC	WRAMC
ARMY	FT RITCHIE	FTRIT
ARMY	CAMERON STATION	CAMST
ARMY	FT BELVOIR	FTBEL
ARMY	FT LESLIE MCNAIR	FTLM
ARMY	FT MYER	FTMYR
ARMY	MOT N CAROLINA	MNC
ARMY	MOT NEW JERSEY	MNJ
ARMY	OAKLAND ARMY BASE	OAKAB
ARMY	FT GREELY	FTGRE
ARMY	FT RICHARDSON	FTRIC

Service	Base_name	Faci_abr
ARMY	FT SHAFTER	FTSHF
ARMY	FT WAINWRIGHT	FTWW
ARMY	CARLISLE BARRACKS	CARBR
ARMY	FT BENJAMIN HARRISON	FTBH
ARMY	FT BENNING	FTBEN
ARMY	FT BLISS	FTBLS
ARMY	FT CHAFFEE	FTCHF
ARMY	FT DIX	FTDIX
ARMY	FT EUSTIS	FTEUS
ARMY	FT GORDON	FTGOR
ARMY	FT HAMILTON	FTHAM
ARMY	FT HUACHUCA	FTHUA
ARMY	FT JACKSON	FTJAC
ARMY	FT KNOX	FTKNX
ARMY	FT LEONARD WOOD	FTLW
ARMY	FT LEAVENWORTH	FTLVW
ARMY	FT LEE	FTLEE
ARMY	FT MC CLELLAN	FTMCL
ARMY	FT MONROE	FTMON
ARMY	FT RUCKER	FTRCK
ARMY	FT SILL	FTSIL
ARMY	WEST POINT MIL ACAD	WPMA
AIR FORCE	AF ACADEMY	AFACD
AIR FORCE	ALTUS AFB	ALAFB
AIR FORCE	ANDREWS AFB	ANAFB
AIR FORCE	ARNOLD AFB	ARAFB
AIR FORCE	BARKSDALE AFB	BKAFB
AIR FORCE	BEALE AFB	BLAFB
AIR FORCE	BOLLING AFB	BOAFB
AIR FORCE	BROOKS AFB	BRAFB
AIR FORCE	CANON AFB	CAAFB
AIR FORCE	CHARLESTON AFB	CHAFB
AIR FORCE	COLUMBUS AFB	CLAFB
AIR FORCE	DAVIS MONTHAN AFB	DMAFB
AIR FORCE	DOVER AFB	DOAFB
AIR FORCE	DYESS AFB	DYAFB
AIR FORCE	EDWARDS AFB	EDAFB
AIR FORCE	EGLIN AFB	EGAFB
AIR FORCE	ELLSWORTH AFB	ELAFB
AIR FORCE	FAIRCHILD AFB	FCAFB
AIR FORCE	FALCON AFB	FLAFB
AIR FORCE	GOODFELLOW AFB	GDAFB
AIR FORCE	GRAND FORKS AFB	GFAFB
AIR FORCE	GRIFFISS AFB	GRAFB
AIR FORCE	GUNTER AFB	GTAFB
AIR FORCE	HANSCOM FIELD	HNFLD
AIR FORCE	HILL AFB	HLAFB
AIR FORCE	HOLLOMAN AFB	HMAFB
AIR FORCE	HURLBURT FIELD	HBFLD

Service	Base_name	Faci_abr
AIR FORCE	K. I. SAWYER AFB	KSAFB
AIR FORCE	KEESLER AFB	KAFB
AIR FORCE	KELLY AFB	KLAFB
AIR FORCE	KIRTLAND AFB	KIAFB
AIR FORCE	LACKLAND AFB	LLAFB
AIR FORCE	LANGLEY AFB	LAFB
AIR FORCE	LAUGHLIN AFB	LHAFB
AIR FORCE	LITTLE ROCK AFB	LRAFB
AIR FORCE	LOS ANGELES AFS	LAAFS
AIR FORCE	LUKE AFB	LUAFB
AIR FORCE	MALMSTROM AFB	MSAFB
AIR FORCE	MARCH AFV	MRAFB
AIR FORCE	MAXWELL AFB	MXAFB
AIR FORCE	MCCHORD AFB	MCAFB
AIR FORCE	MCCLELLAN AFB	MLAFB
AIR FORCE	MCCONNELL AFB	MNAFB
AIR FORCE	MCGUIRE AFB	MGAFB
AIR FORCE	MINOT AFB	MTAFB
AIR FORCE	MOODY AFB	MDAFB
AIR FORCE	MOUNTAIN HOME	MTNHM
AIR FORCE	NELLIS AFB	NLAFB
AIR FORCE	NEWARK AFS	NWAFB
AIR FORCE	OFFUTT AFB	OFAFB
AIR FORCE	ONIZUKA AFS	OZAFB
AIR FORCE	PATRICK AFB	PKAFB
AIR FORCE	PETERSON AFB	PRAFB
AIR FORCE	PLATTSBURGH AFB	PBAFB
AIR FORCE	POPE AFB	PPAFB
AIR FORCE	RANDOLPH AFB	RDAFB
AIR FORCE	REESE AFB	RSAFB
AIR FORCE	ROBINS AFB	RBAFB
AIR FORCE	SCOTT AFB	SCAFB
AIR FORCE	SEYMOUR JOHNSON AFB	SJAFB
AIR FORCE	SHAW AFB	SHAFB
AIR FORCE	SHEPPARD AFB	SPAFB
AIR FORCE	TINKER AFB	TNAFB
AIR FORCE	TRAVIS AFB	TRAFB
AIR FORCE	TYNDALL AFB	TYAFB
AIR FORCE	VANCE AFB	VAFB
AIR FORCE	VANDENBERG AFB	VBAFB
AIR FORCE	WARREN AFB	WAFB
AIR FORCE	WRIGHT-PATTERSON AFB	WPAFB
NAVY	ADAK	ADAK
NAVY	LEMOORE	LEM
NAVY	PORT HUENEME/PT.MA	PHPM
NAVY	CHINA LAKE	CLAKE
NAVY	NEW LONDON	NWLON
NAVY	JACKSONVILLE	JACK
NAVY	ORLANDO	ORLND

Service	Base_name	Faci_abr
NAVY	PENSACOLA	PENSA
NAVY	KEY WEST	KYWST
NAVY	KINGS BAY	KGBAY
NAVY	ALBANY	ALBNY
NAVY	PEARL HARBOR	PLHAR
NAVY	GREAT LAKES	GLAKE
NAVY	INDIANAPOLIS	INDPL
NAVY	CRANE NWSC	CNWSC
NAVY	LOUISVILLE	LOUIS
NAVY	LOS ANGELES AREA	LAARE
NAVY	N. ORLEANS	NORLS
NAVY	BRUNSWICK	BRUNS
NAVY	ANNAPOLIS	ANNAP
NAVY	INDIAN HEAD	INDHD
NAVY	PATUXENT RIVER	PATUX
NAVY	MERIDIAN NAS	MRNAS
NAVY	GULFPORT	GULFP
NAVY	FALLON	FALLN
NAVY	TRENTON	TRENT
NAVY	LAKEHUST	LAKEH
NAVY	COLTS NECK	CLTSN
NAVY	BETHPAGE	BETHP
NAVY	N.Y. CITY	NYCTY
NAVY	NORFOLK	NRFLK
NAVY	CHERRY POINT	CHRPT
NAVY	MECHANICSBURG	MECHB
NAVY	WARMINSTER	WARMR
NAVY	PHILADELPHIA	PHILA
NAVY	NEWPORT	NEWPT
NAVY	MIRAMAR	MIRMR
NAVY	SAN DIEGO	SNDGO
NAVY	MARE ISLAND	MRISL
NAVY	SAN FRANCISCO	SNFRN
NAVY	MOFFETT FIELD	MOFFD
NAVY	OAKLAND	OAKLD
NAVY	ALAMEDA NARF	AMARF
NAVY	OAKLAND HOSPITAL	OKHSP
NAVY	BEAUFORT/PARRIS IS	BFTPI
NAVY	CHARLESTON	CHARL
NAVY	MEMPHIS	MEMPH
NAVY	DALLAS	DALLS
NAVY	CORPUS CHRISTI	CORPC
NAVY	DAHLGREN	DAHLG
NAVY	YORKTOWN	YORKT
NAVY	WASHINGTON D.C.	WSHDC
NAVY	WHIDBEY IS.	WHIDI
NAVY	SEATTLE	SEATL
MARINES	YUMA	YUMA
MARINES	CAMP PENDLETON	CAMPP

Service	Base_name	Faci_abr
MARINES	BARSTOW	BRSTW
MARINES	TWENTYNINE PALMS	TNPLM
MARINES	CAMP LEJEUNE	CMPLJ
MARINES	QUANTICO	QUANT
		GNRIC

Appendix B: Details of Analyses of ECOs

B.1 ECOs for LAP Process at IWAAP for Producing M106 Shells

ECO SUMMARY FORM

PROCESS CATEGORY: LAP Process

SPECIFIC PROCESS: LAP M106 Shells at IWAAP

DESCRIPTION OF ECO: **Automatically Control Process Heat**
To assure the heat producing equipment's being at the proper temperature at the beginning of a shift, steam must be left on during off-shift hours. Substantial energy could be saved by the use of a timer-controller to heat the equipment to the proper temperature by the beginning of a shift.

ASSUMPTIONS: For the annual production of M106 shells, the savings in steam could be an estimated 1,540 MBtu/yr of steam (11,700 Btu per M106 shell produced). This saving in steam was estimated (see ref.) as the sum of the amount of steam consumed by each of a number of pieces of equipment (preheat oven, grid melt unit, Dopp kettle, steam probe, and hot-water probe) during non-use hours over the course of 50 weeks for the year (multiplied by a factor of 85 percent, assuming that this portion of the steam could be saved).

CALCULATION OF BASELINE ENERGY AND EMISSIONS:

		Btu/shell	
	Baseline	Saving	New Energy Consumption
Preheat oven (No. 2)	7,455	4,763	2,692
Grid melt unit (4)	8,273	2,858	5,415
Dopp kettle (also 4)			
Steam probe (5)	6,000	4,049	1,951
Hot water probe (5)			
	21,728	11,670	10,058

This ECO has no impact on process emissions.

Ref.: *Process Energy Inventory at IWAAP, Load Line 3*, Contractor Report ARLCD-CR-81016 (September 1981).

CALCULATION OF ECO ENERGY AND EMISSIONS:

See above table.

COST DATA:

Capital Cost: each of 5 controllers assumed to cost $2,000 (for engineering) + $500 (hardware—electronic programmable controller), total is 5 x $2,500 = $12,500
Annual O&M Savings: No impact.

Based on information from D.Beauchesne, Despatch Oven Company, to M.Fraser, SAIC.

ECO SUMMARY FORM

PROCESS CATEGORY: LAP Process

SPECIFIC PROCESS: LAP M106 Shells at IWAAP

DESCRIPTION OF ECO: <u>**Insulate Heat Producing Equipment and Piping**</u>
A significant amount of energy could be saved by devising a suitable method for insulating certain process equipment and piping. A large quantity of equipment such as melt kettles, melt grid units, volumetric loaders, etc. as well as steam-jacketed explosives piping, steam piping, and hot-water piping is currently not insulated.

CALCULATION OF BASELINE ENERGY AND EMISSIONS: An analysis was made by IWAAP to estimate the heat energy that could be saved by insulating this equipment. Based on the estimated amount of hot surface areas of process equipment, process piping, and heating system piping, the amounts of heat lost without and with insulation were estimated. Insulating the process piping with 3 in. of insulation was estimated to save 394 MBtu/yr in steam (2,985 Btu per M106 shell produced) at an estimated cost of $20,300 (in 1995 $), insulating the heating system piping 438 MBtu/yr (3,318 Btu per M106 shell produced) at a cost of $37,000, and insulating the process equipment 167 MBtu/yr (1,265 Btu per M106 shell produced) at a cost of $4,900. This ECO has no impact on process emissions.

Ref.: "Process Energy Inventory at IWAAP, Load Line 3," Contractor Report ARLCD-CR-81016, September 1981.

CALCULATION OF ECO ENERGY AND EMISSIONS:

See above.

COST DATA:

Capital Cost: The capital-cost estimates given in the reference were updated to 1995 $ using appropriate values of the Marshall & Swift equipment cost index. See above.
Annual O&M Savings: No impact.

Note: These cost estimates included insulation for a number of pieces of equipment that are difficult to assign to specific process operations. Therefore, the estimates for energy savings and costs were included in the PEPR representations of these ECOs as an extra operation with a capital cost and negative energy consumption (saving).

ECO SUMMARY FORM

PROCESS CATEGORY: LAP Process

SPECIFIC PROCESS: LAP M106 Shells at IWAAP

DESCRIPTION OF ECO:

Substitute Natural Gas for Steam in Post-Cyclic Heating Operation

Piping steam from the central steam supply to provide steam to the ovens used for post-cyclic heating appears to be inefficient. Converting the ovens to use natural gas for heating would make these heating operations cheaper and more efficient.

ASSUMPTIONS:

1. The same number of Btus supplied by steam will now be supplied by natural gas (divided by the assumed efficiency for combustion of natural gas in this application of 85 percent). (Note: In the final analysis of the cost of energy as steam, there is a fuel-to-steam efficiency at the boiler as well as the fact that the number of Btus of steam required to be generated at the boiler—and charged to the process in the final economic analysis—equals the process consumption divided by (1 - loss factor).)

2. It is assumed that it is feasible to retrofit the present ovens. They should be less than 10 years old and of at least a medium size.

CALCULATION OF BASELINE ENERGY AND EMISSIONS:

The post-cyclic heating operation is estimated to consume 49,242 Btu in steam per M106 shell.

This ECO has no impact on process emissions.

CALCULATION OF ECO ENERGY AND EMISSIONS:

Btus of natural gas required are 49,242/0.85 = 57,932.

COST DATA:

Capital Cost: engineering cost $3,000-5,000; up to $10,000 for the hardware. (Cost put into PEPR data base: $13,000.)

Annual O&M Savings: No impact.

Based on information from D.Beauchesne, Despatch Oven Company, to M.Fraser, SAIC.

B.2 ECOs for Nitrocellulose Production Process

ECO SUMMARY FORM

PROCESS CATEGORY: Explosives

SPECIFIC PROCESS: Nitrocellulose at RFAAP

DESCRIPTION OF ECO:
Substitute Natural Gas for Steam in Feedstock Drying Operation
Using high-pressure steam from the central steam supply to provide heat to the dryer used to dry feedstock appears to be inefficient. Converting this dryer to use natural gas for heating would make this drying operation cheaper and more efficient.

ASSUMPTIONS:

1. The same number of Btus estimated to be supplied by steam will now be supplied by natural gas (divided by the assumed efficiency for combustion of natural gas in this application of 85 percent). (Note: In the final analysis of the cost of energy as steam, there is a fuel-to-steam efficiency at the boiler as well as the fact that the number of Btus of steam required to be generated at the boiler—and charged to the process in the final economic analysis—equals the process consumption divided by (1 - loss factor).)

2. It is assumed that it is feasible to retrofit the present dryer. They should be less than 10 years old and of at least a medium size.

CALCULATION OF BASELINE ENERGY AND EMISSIONS:

The feedstock heating operation is estimated to consume 280 Btu in steam per lb of nitrocellulose (based on amount of water evaporated and typical 15 percent efficiency of drying operation).

This ECO has no impact on process emissions.

CALCULATION OF ECO ENERGY AND EMISSIONS:

Btus of natural gas required are 280/0.85 = 330 Btu/lb NC product.

COST DATA:

Capital Cost: engineering cost $3,000-5,000; up to $10,000 for the hardware. (Cost put into PEPR data base: $13,000.)
Annual O&M Savings: No impact.

Based on information from D.Beauchesne, Despatch Oven Company, to M.Fraser, SAIC.

ECO SUMMARY FORM

PROCESS CATEGORY: Explosives

SPECIFIC PROCESS: Nitrocellulose at RFAAP

DESCRIPTION OF ECO:
Insulate Boiling and Poacher Tubs
The boiling and poacher tubs appear to be uninsulated at present, resulting in a significant loss of thermal energy during the extended periods of washing at boiling temperature. Insulating these tanks is a difficult proposition because they must be washed down periodically to prevent the accumulation of NC fines. A system for insulating the tanks that maintains the washability of the process equipment was designed and estimated relatively recently for decreasing these heat losses.

ASSUMPTIONS:
Tub dimensions: 18 ft diameter, 12 ft high; steel thickness 0.25 in
Surface areas: top = 254 sq ft, bottom = 254 sq ft, sides = 679 sq ft
$T_{outside}$ = 62 °F; T_{inside} = 212 °F

No impact on emissions.

CALCULATION OF BASELINE ENERGY AND EMISSIONS:
Tub heat loss without insulation
Q = UAΔT = 0.74 x 679 x 150 + 0.91 x 254 x 150 + 0.37 x 254 x 150 = 124,137 Btu/hr

Tubs assumed to operate 75 percent of the time (8,760 hr/yr x 0.75 = 6,570 hr/yr).

CALCULATION OF ECO ENERGY AND EMISSIONS:
Tub heat loss with insulation
Q = UAΔT = 0.10 x 679 x 150 + 0.096 x 254 x 150 + 0.37 x 254 x 150 = 27,940 Btu/hr

Saving = 96,197 Btu/hr per tub;
Annual savings for 8 tubs:
96,197 Btu/hr-tub x 8 tubs x 6,570 hr/yr = 5056.1 MBtu/yr
(2.528 MBtu/hr average saving per hour of production)

COST DATA AND ECONOMIC ANALYSIS:
Capital Cost: $8,326 x 1.127 (index) = $9,383 each tub; 5 boiling tubs and 3 poachers;
$9,383 x 8 = $75,064
Annual O&M Savings: NA

Ref.: Reynolds, Smith, and Hills, Inc., *Energy Surveys of Army Industrial Facilities, Energy Engineering Analysis Program, Radford Army Ammunition Plant*, Executive Summary, Report to U.S. Army Corps of Engineers, Contract No. DACA65-86-C-0154 (March 1991).

ECO SUMMARY FORM

PROCESS CATEGORY: Explosives

SPECIFIC PROCESS: Nitrocellulose at RFAAP

DESCRIPTION OF ECO:

Recover Heat via Heat Exchanger to Preheat Incoming Water

When one batch of hot water is dumped at the end of a wash cycle, it can be pumped through a heat exchanger located in another washing tub to preheat another batch, thus saving on the amount of steam needed to heat this next batch to boiling.

ASSUMPTIONS:

There are 13 tubs that could benefit from this system.

CALCULATION OF BASELINE ENERGY AND EMISSIONS:

Data show that a tub on boil consumes 1.654 MBtu/hr-tub (1,408 lb/hr of 40-psig steam @ 1175 Btu/lb).

A tub is on boil 75 percent of the time or 6,570 hr/yr.

CALCULATION OF ECO ENERGY AND EMISSIONS:

A heat exchanger would save 78.2 percent of the energy required:

0.782 x 1.654 MBtu/hr-tub x 0.75 x 8,760 hr/yr = 8498 MBtu/yr-tub

No. of tubs used per year:

28,000,000 lb NC produced/yr ÷ 30,000 lb NC/tub cycle = 930 tub cycles/yr

(930 tub cycles/yr x 100 hr/cycle) ÷ 8,760 hr/yr ≈ 11 tubs

Total energy savings = 11 tubs x 8498 MBtu/yr-tub = 93,478 MBtu/yr

(46.74 MBtu per average hour of operation)

COST DATA AND ECONOMIC ANALYSIS:

Capital Cost: $8,923/tub x 1.127 (index) = $10,056/tub; 13 tubs x $10,056/tub = $130,700

Annual O&M Savings: NA

Ref.: Reynolds, Smith, and Hills, Inc., *Energy Surveys of Army Industrial Facilities, Energy Engineering Analysis Program, Radford Army Ammunition Plant*, Executive Summary, Report to U.S. Army Corps of Engineers, Contract No. DACA65-86-C-0154 (March 1991).

B.3 ECOs for Vehicle Drive-Through Paint Booth at RIARS

ECO SUMMARY FORM

PROCESS CATEGORY: Paint Booth

SPECIFIC PROCESS: Vehicle Drive-Through Paint Booth at RIARS

DESCRIPTION OF ECO:

Decrease the Amount of Air Circulation

The specifications for air circulation for an operating booth are generally subject to regulations regarding minimum air flow. However, since the booth was originally designed, the air circulation system may not have been maintained, and the amount of air being circulated may be more than is required. The fans may be oversized and are circulating more air than is necessary. In addition, if low-volatile-content paints are being used, less VOCs are being emitted that have to be ventilated from the booth. Thus, the amount of air being circulated should be measured and controlled at the absolute minimum. Perhaps the amount of air being circulated can be reduced.

ASSUMPTIONS:

As an example of the potential savings through better control of the air circulation, assume that the amount of air being circulated can be reduced by 10 percent.

CALCULATION OF BASELINE ENERGY AND EMISSIONS:

Once-through air flow through booth during operation = 120,000 cfm
Paint booth exhaust flues: 1 @ 53 x 10 in., 3 @ 30-in. diameter = 18.4 sq ft
Infiltration rate = 9.2 mph x 0.5 opening coeff. x 88 fpm/mph = 405 fpm
Constant = 1.08 Btu/hr required to raise temperature of 1 cfm of air 1 °F
Scheduled occupancy = 40 hr/wk
Average temperatures = 75 °F (inside when booth is used), 55 °F (inside when booth is not used), 32 °F (outside during heating season)
Average heating season length = 28 weeks

Energy to heat once-through air during hours of operation:
120,000 cfm x 1.08 Btu/hr-cfm- °F x (75-32) °F x 40 hr/wk x 28 wk/yr = 6,241.5 MBtu/yr
(3.12 MBtu/average hour of operation)
Energy to heat air infiltration during nonoperating hours:
18.4 sq ft x 405 fpm x 1.08 Btu/hr-cfm- °F x (55-32) °F x 128 hr/wk x 28 wk/yr =
663.4 MBtu/yr (0.332 MBtu/average hour of operation)

Emissions were calculated assuming 1 gal of paint sprayed per hour.

CALCULATION OF ECO ENERGY AND EMISSIONS:

Energy saved by being able to reduce the air circulation by 10 percent:

0.1 x 6,241.5 MBtu/yr = 624.1 MBtu/yr (0.312 MBtu/average hour of operation)

COST DATA:

Capital Cost: $0 (controller on fan speed may be required at a relatively small cost)

Annual O&M Savings: NA

ECO SUMMARY FORM

PROCESS CATEGORY: Paint Booth

SPECIFIC PROCESS: Vehicle Drive-Through Paint Booth at RIARS

DESCRIPTION OF ECO:

Consider the Use of HVLP Spray Guns

An HVLP spray gun is a more efficient painting system with considerably less paint used, less paint waste, and fewer VOCs emitted to the atmosphere. Investigate the use of HVLP guns for specific types of paints and specific spray paint booths.

ASSUMPTIONS:

For the conventional (low-volume, high-pressure) spray guns, a transfer efficiency of 40 percent was assumed (60 percent of the paint and its solids comprise the overspray and particulate emissions [TSP], to be controlled by either a dry filter or a waterfall). PM_{10} emissions are 100 percent of TSP for a dry filter and 50 percent of TSP for a waterfall booth. VOC and volatile HAP emissions (usually not controlled) are assumed to equal the amount of each in the quantity of paint used.

CALCULATION OF BASELINE ENERGY AND EMISSIONS:

Property and Emission Type	Paint Composition (polyurethane)	Conventional Emissions lb/gal of paint (1 gal sprayed/hr)		HVLP Emissions** 1 hour of operation (same amt. paint on part)	
		Uncon-trolled	Controlled	Uncontrolled	Controlled
Density	11.68 lb/gal				
Solids	35.0%				
TSP		2.45	0.049*	1.56	0.031
PM_{10}		1.23	0.025*	0.78	0.016
VOCs	62.0%	7.24	7.24	3.87	3.87
HAPs					
Xylene	5.0%	0.58	0.58	0.31	0.31
Methyl ethyl ketone	10.0%	1.17	1.17	0.62	0.62
Chromium compounds	10.0%	0.70	0.014*	0.16	0.003
Toluene	5.0%	0.58	0.58	0.31	0.31

*Assuming 98% control of particulates and 50% of particulate emissions is PM_{10}.

**To get the same amount of paint on the part, the HVLP gun should use only 0.53 gal of paint compared to 1 gal of paint with a conventional spray gun, resulting in a considerable saving in paint.

CALCULATION OF ECO ENERGY AND EMISSIONS:
A HVLP spray gun uses compressed air at a lower pressure than does a conventional spray gun. However, to realize this potential energy saving, which is small, the supply of compressed air would have to be reduced in pressure or otherwise revamped, which may not be done. Usually, the compressed air is simply throttled to the lower pressure of the HVLP gun.

COST DATA:

Capital Cost: $285 (for the HVLP gun)
Annual O&M Savings: 5.45 lb paint saved/hr x 2000 hr/yr x $2/lb of paint = $21,800

ECO SUMMARY FORM

PROCESS CATEGORY: Paint Booth

SPECIFIC PROCESS: Vehicle Drive-Through Paint Booth at RIARS

DESCRIPTION OF ECO:
Consider Converting a Water-Wash Booth to a Dry Filter
Cleaning the paint sludge out of the washwater pit in a water-wash paint booth can be expensive and lead to the generation of hazardous waste. Investigate the cost-effectiveness of converting the booth to a dry-filter system.

ASSUMPTIONS:
This ECO has very little effect on energy usage. It does eliminate the pumping power required to circulate water in a booth with a water curtain. The main advantage of this ECO is that it seems to be a cheaper way of controlling the particulate emissions in the air circulated through the booth. Eliminated are the costs for water treatment chemicals, disposal of hazardous waste (wet paint sludge), and periodic pit cleaning. However, according to a paint booth manufacturer, a dry filter is not quite as effective at controlling particulates as is a water curtain.

CALCULATION OF BASELINE ENERGY AND EMISSIONS:
NA

CALCULATION OF ECO ENERGY AND EMISSIONS:
NA

COST DATA:

Capital Cost: $1,670 **Annual O&M Savings:** $22,451

Ref.: Personal communication from Tera Hill, Rock Island Arsenal, to Malcolm Fraser, SAIC.

ECO SUMMARY FORM

PROCESS CATEGORY: Paint Booth

SPECIFIC PROCESS: Vehicle Drive-Through Paint Booth at RIARS

DESCRIPTION OF ECO:

Consider Installing a CentriClean System in Large Water-Wash Paint Booth

In the conventional design of a booth using a water-wash system, the water is recirculated. Chemicals suitable for the specific material being sprayed are added to the water bath to treat the water and to coagulate the paint particles. The cost of the chemicals, the cost to clean out and dispose of the coagulated paint sludge, the cost of system downtime for cleaning, and the cost of treating wastewater can all add up to a considerable total cost to operate a water-wash-type of spray paint booth. As an alternative to the conventional way of operating a water-wash booth, there is a simple and innovative sludge dewatering system now available for automatically dewatering, compacting, and discharging paint solids from water-wash spray booths. This system is called the CentriClean (Binks Manufacturing Company) Sludge Dewatering System (other companies have comparable systems).

Four different models are available, depending on the desired rate of water throughput in gpm, costing from $6,545 to $44,265. The two larger units are used for operations that usually spray more than 30 gal of paint a day.

ASSUMPTIONS:

Assume that a Binks Model C-100A has sufficient capacity for the subject paint booth. This model runs completely automatically, with the paint sludge put into drums ready to haul away.

CALCULATION OF BASELINE ENERGY AND EMISSIONS:

NA

CALCULATION OF ECO ENERGY AND EMISSIONS:

The CentriClean machine requires electrical power (3-hp motor) for an added consumption of electricity of 7,635 Btu/hr when the booth is operating.

COST DATA:

Capital Cost: $32,985 **Annual O&M Savings:** $23,105

Use of a CentriClean eliminates all of the annual costs required to clean the paint pit except for hazardous waste disposal costs.

Ref.: 1. Private communications between Tera Hill, Rock Island Arsenal, and Malcolm Fraser, Science Applications International Corporation (June 1995).

2. Private communications between Benjamin Mallen, Binks Manufacturing Company, and Malcolm Fraser, SAIC (May 1995).

ECO SUMMARY FORM

PROCESS CATEGORY: Paint Booth

SPECIFIC PROCESS: Vehicle Drive-Through Paint Booth at RIARS

DESCRIPTION OF ECO:

Install Automatic Dampers to Close the Exhaust Ducts

Whenever the air circulation system in the booth is turned off, there is a draft through the open ducts and infiltration of untempered outside air to lose heat. Install automatic dampers in the exhaust ducts to close off the ducts whenever the exhaust fans are not running.

ASSUMPTIONS:

Air flow through booth during operation = 120,000 cfm
Paint booth exhaust flues: 1 @ 53 x 10 in., 3 @ 30-in. diameter = 18.4 sq ft
Infiltration rate = 9.2 mph x 0.5 opening coeff. x 88 fpm/mph = 405 fpm
Constant = 1.08 Btu/hr required to raise temperature of 1 cfm of air 1 °F
Scheduled occupancy = 40 hr/wk
Average temperatures = 75 °F (inside when booth is used), 55 °F (inside when booth is not used), 32 °F (outside during heating season)
Average heating season length = 28 weeks
Damper efficiency = 90 percent

CALCULATION OF BASELINE ENERGY AND EMISSIONS:

Energy to heat make-up air during hours of operation:
120,000 cfm x 1.08 Btu/hr-cfm- °F x (75-32) °F x 40 hr/wk x 28 wk/yr = 6,241.5 MBtu/yr
(3.12 MBtu/average hour of operation)
Energy to heat air infiltration during nonoperating hours:
18.4 sq ft x 405 fpm x 1.08 Btu/hr-cfm- °F x (55-32) °F x 128 hr/wk x 28 wk/yr =
663.4 MBtu/yr (0.332 MBtu/average hour of operation)

Emissions were calculated assuming 1 gal of paint sprayed per hour.

CALCULATION OF ECO ENERGY AND EMISSIONS:

Energy is saved on the heat required to heat the unfiltered air during nonoperating hours:
Energy saved = 0.9 x 663.4 MBtu/hr = 597.1 MBtu/yr (0.299 MBtu/average hour of operation)

No impact on baseline emissions.

COST DATA:

Capital Cost: $6,700. **Annual O&M Savings:** NA

Ref.: 1. Campbell Design Group, *Energy Survey of Industrial Facilities, Rock Island Arsenal*, Contract No. DACA27-88-C-0002 (June 1989).

B.4 ECOs for Electroplating Shop at RBAFB

ECO SUMMARY FORM

PROCESS CATEGORY: Electroplating Shop

SPECIFIC PROCESS: Electroplating Shop (variety of processes lumped together)

DESCRIPTION OF ECO:

Reduce 100-Percent Overplating

Frequently, parts are overplated up to 100 percent to allow for an adequate thickness for uniform grinding. However, this amount of overplating would appear to waste energy and materials; overplating should be controlled at a lower level—say, 50 percent—for conservation.

ASSUMPTIONS:

Assume four chrome-plating tanks (operated at 135 °F)

By reducing overplating from 100 to 50 percent, plating tanks are operated for only 0.75 of the hours they are operated currently (saving 25 percent of the electricity and steam).

Savings of energy are in electricity, compressed air, and steam not used for the hours of operation saved.

CALCULATION OF BASELINE ENERGY AND EMISSIONS:

Baseline electricity is 24,600 Btu/hr of operation per tank (9 V, 2 A/sq in, 400 sq in plating area). Annual electricity consumption for plating is:

4 tanks x 24,600 Btu/hr x 8,760 hr/yr x 0.5 util. factor = 431 MBtu/yr

Steam consumption is 41,000 Btu/hr per tank:

4 tanks x 41,000 Btu/hr x 8,760 hr/yr x 0.5 util. factor = 718.3 MBtu/yr

Compressed air consumption:

4 tanks x 80 cfm x 8.5 Btu/cf x 60 min/hr x 8,760 hr/yr x 0.5 util. factor = 714.8 MBtu/yr

CALCULATION OF ECO ENERGY AND EMISSIONS:

Electricity saved is 0.25 x 431 MBtu/yr = 107.8 MBtu/yr (12,300 Btu/hr average)

Steam saved is 0.25 x 718.3 MBtu/yr = 179.6 MBtu/yr (20,500 Btu/hr average)

Compressed air saved is 0.25 x 714.8 MBtu/yr = 178.7 MBtu/yr (20,400 Btu/hr average)

COST DATA:

Capital Cost: $0 **Annual O&M Savings:** NA

ECO SUMMARY FORM

PROCESS CATEGORY: Electroplating Shop

SPECIFIC PROCESS: Electroplating Shop (variety of processes lumped together)

DESCRIPTION OF ECO:

Replace Air Agitation with Electric Agitation in Tanks

Compressed air is typically used for agitating solutions in plating tanks. Although the use of compressed air for this purpose is convenient, compressed air is a very inefficient way to use energy. Electric agitators should be considered to eliminate the use of compressed air for this purpose.

ASSUMPTIONS:

Assume 20 tanks agitated x 80 cfm @ 20 hp/100cfm x 0.5 util. factor
Air agitation is replaced by 2 1-hp paddle mixers per tank

CALCULATION OF BASELINE ENERGY AND EMISSIONS:

20 tanks agitated x 80 cfm x 8.5 Btu/cf x 60 min/hr x 8,760 hr/yr x 0.5 util. factor =
3,574 MBtu/yr (408,000 Btu/hr average)

CALCULATION OF ECO ENERGY AND EMISSIONS:

Each tank has 2 mixers consuming 5,090 Btu/hr of operation
20 tanks agitated x 5,090 Btu/hr x 8,760 hr/yr x 0.5 util. factor =
445.9 MBtu/yr (50,900 Btu/hr average)
Saving is 408,000 - 50,900 = 357,100 Btu/hr on average

COST DATA:

Capital Cost: 20 tanks x 2 mixers/tank x $3,500 = $140,000.
Annual O&M Savings: NA

Ref.: Personal communication between APV Company and V. Gorokhov, SAIC.

ECO SUMMARY FORM

PROCESS CATEGORY: Electroplating Shop

SPECIFIC PROCESS: Electroplating Shop (variety of processes lumped together)

DESCRIPTION OF ECO:

Float Polypropylene Balls on Top of Solutions to Reduce Heat Losses

Uncovered, hot solutions in plating tanks can lose a significant amount of energy through increased evaporation and heat loss. Balls floated on top of the hot solutions in heated tanks can reduce these heat losses by a significant amount.

ASSUMPTIONS:

Install layer of floating balls on surface of solution in each heated vat.
Layer of balls cuts surface heat losses in half.
Warm tanks: 11 tanks at 130 °F (between 100 to 155 °F) operated 1/2 time
Hot tanks: 20 tanks at average of 180 °F operated 1/2 time

CALCULATION OF BASELINE ENERGY AND EMISSIONS:

11 tanks at 130 °F x 41,000 Btu/hr of operation x 8,760 hr/yr x 0.5 util. factor =
1,975.4 MBtu/yr (225,500 Btu/hr average)
20 tanks at 180 °F x 131,120 Btu/hr of operation x 8,760 hr/yr x 0.5 util. factor =
11,486 MBtu/yr (1,311,200 Btu/hr average) operated 1/2 time

CALCULATION OF ECO ENERGY AND EMISSIONS:

11 tanks at 130 °F x 25,420 Btu/hr of operation x 8,760 hr/yr x 0.5 util. factor =
1,224.7 MBtu/yr (139,800 Btu/hr average)
20 tanks at 180 °F x 76,120 Btu/hr of operation x 8,760 hr/yr x 0.5 util. factor =
6,668.1 MBtu/yr (761,200 Btu/hr average) operated 1/2 time
Total saving = 225,500 + 1,311,200 - 139,800 - 761,200 = 635,700 Btu/hr

COST DATA:

Capital Cost: $2/sq ft x 31 tanks x 40 sq ft = $2,500.
Annual O&M Savings: NA

ECO SUMMARY FORM

PROCESS CATEGORY: Electroplating Shop

SPECIFIC PROCESS: Electroplating Shop (variety of processes lumped together)

DESCRIPTION OF ECO:

Eliminate Use of Steam for Heating Tanks and Replace with Natural Gas

The use of steam—particularly the 125-150 psi steam from the central steam supply with all of the inefficiencies of that system—is an inefficient and unnecessary way to warm the solutions in plating tanks. A system can be engineered to use natural gas for heating each tank.

ASSUMPTIONS:

Natural gas used directly for heating tanks has an efficiency of 90 percent.

CALCULATION OF BASELINE ENERGY AND EMISSIONS:

11 tanks at 130 °F x 41,000 Btu/hr of operation x 8,760 hr/yr x 0.5 util. factor =
1,975.4 MBtu/yr (225,500 Btu/hr average)

20 tanks at 180 °F x 131,120 Btu/hr of operation x 8,760 hr/yr x 0.5 util. factor =
11,486 MBtu/yr (1,311,200 Btu/hr average) operated 1/2 time

CALCULATION OF ECO ENERGY AND EMISSIONS:

Total energy in steam = 225,500 + 1,311,200 = 1,536,700 Btu/hr (average)

Total gas required = 1,536,700/0.9 efficiency = 1,707,444 Btu/hr (average)

COST DATA:

Capital Cost:

For each tank two burners @ $2108 + temp. control @ $608 = $5,000.
31 tanks x $5,000 = $155,000.

Annual O&M Savings: NA

B.5 ECOs for Quench and Temper Heat-Treating Process

ECO SUMMARY FORM

PROCESS CATEGORY: Heat Treating

SPECIFIC PROCESS: Quench and Temper Process for Ferrous Parts at ANAD

DESCRIPTION OF ECO:

Install Improved Seals on Furnace Doors

Since a furnace operates at a temperature higher than ambient, air may be drawn into the combustion chamber through any cracks and crevices due to the stack effect. Such air allowed to infiltrate into the furnace is detrimental to the furnace efficiency. Energy can be saved through the use of effective door seals.

ASSUMPTIONS:

Energy savings estimated from reduction in infiltration around the door of 50 percent.

CALCULATION OF BASELINE ENERGY AND EMISSIONS:

Quench furnace:

1. Consumes 1.4 MBtu/hr (the maximum) for 20 hr/wk x 50 wk/yr = 1000 hr/yr
2. Consumes 1.0 MBtu/hr idling at 1600 °F for 20 hr/wk x 50 wk/yr = 1000 hr/yr
3. Consumes 0.8 MBtu/hr turned down to 1400 °F for 8760 - 2000 = 6760 hr/yr
4. Total energy 7808.0 MBtu/yr (average 0.891 MBtu/hr)

Draw furnace:

1. Consumes 1.4 MBtu/hr (the maximum) for 12 hr/wk x 50 wk/yr = 600 hr/yr
2. Consumes 0.4 MBtu/hr idling at 1000 °F for 92 hr/wk x 50 wk/yr = 4600 hr/yr
3. Consumes 0.1 MBtu/hr turned down to 300 °F for 8760 - 5200 = 3560 hr/yr
4. Total energy 3036.0 MBtu/yr (average 0.347 MBtu/hr)

No information on emissions.

CALCULATION OF ECO ENERGY AND EMISSIONS:

Avg. furnace door perimeter = 18 LF
Infiltration rate = 0.5 cfm/LF
Infiltration reduction with door seals = 50 percent
Constant = 1.08 Btu/hr to raise temperature of 1 cfm of air by 1 °F
Furnace temperature = 1446 °F (quench), 715 °F (draw)
Ambient temperature = 75 °F
Quench: 18 LF x 0.5 cfm/LF x 0.5 x 1.08 Btu/hr-cfm- °F x (1446-75) °F =
0.0067 MBtu/hr average saving
Draw: 18 LF x 0.5 cfm/LF x 0.5 x 1.08 Btu/hr-cfm- °F x (715-75) °F = 0.0031 MBtu/hr av saving

COST DATA:
Capital Cost: $4,600 each furnace
Annual O&M Savings: No impact.

Ref.: Campbell Design Group, *Energy Survey of Industrial Facilities, Rock Island Arsenal*, Contract No. DACA27-88-C-0002 (June 1989).

ECO SUMMARY FORM

PROCESS CATEGORY: Heat Treating

SPECIFIC PROCESS: Quench and Temper Process for Ferrous Parts at ANAD

DESCRIPTION OF ECO:

Design Heat Recovery System to Use Hot Exhaust for Preheat

Heat can conceivably be recovered from hot furnace exhaust gases by using them to preheat cold charges prior to heat treatment. The hot exhaust gases would be ducted into an insulated chamber containing the cold charge before being loaded into the furnace. The same type of insulated chamber could be used to prevent heat losses from hot charges (works-in-process) from being dissipated into the shop atmosphere between processes.

ASSUMPTIONS:

It is assumed that this system is implemented after recuperators have been installed. The recuperators are assumed to recover half of the waste heat in the exhaust, and this heat recovery system is assumed to recover half of the remaining energy (i.e., assume an air-to-air heat exchange efficiency of 50 percent).

CALCULATION OF BASELINE ENERGY AND EMISSIONS:

Quench furnace:

1. Consumes 1.4 MBtu/hr (the maximum) for 20 hr/wk x 50 wk/yr = 1000 hr/yr
2. Consumes 1.0 MBtu/hr idling at 1600 °F for 20 hr/wk x 50 wk/yr = 1000 hr/yr
3. Consumes 0.8 MBtu/hr turned down to 1400 °F for 8760 - 2000 = 6760 hr/yr
4. Total energy 7808.0 MBtu/yr (average 0.891 MBtu/hr)

This ECO operates only during the work shift (40 hr/wk with a utilization factor of 0.2).
Gross heating value = 22,800 Btu/lb
Specific weight = 0.044 lb/cu ft gas
Air required for combustion = 9.7 cu ft air/cu ft gas
Constant = 1.08 Btu/hr to raise temperature of 1 cfm of air by 1 °F

(1.0 MBtu/hr/22,800 Btu/lb/0.044 lb/cu ft gas) x 9.7 cu ft air/cu ft gas x (1.08 Btu/hr-cfm-°F/60 min/hr) x (1600-75) °F x 0.5 efficiency = 0.133 MBtu/hr saved via recuperators

CALCULATION OF ECO ENERGY AND EMISSIONS:

Energy saved = 50 percent of remaining waste heat x 0.2 x 40 hr/wk x 50 wk/yr
0.5 x 0.133 MBtu/hr x 0.2 x 40 hr/wk x 50 wk/yr = 26.6 MBtu/yr (avg. 3036 Btu/hr)

Electrical energy to operate blower in heat recovery device:
0.75 hp x 0.7457 kW/hp x 3413 Btu/kWh x 0.2 (util. factor) x 40 hr/wk x 50 wk/yr = 0.764 MBtu/yr (avg. 87 Btu/hr)

COST DATA:
Capital Cost: $15,500
Annual O&M Savings: No impact.

Ref.: Campbell Design Group, *Energy Survey of Industrial Facilities, Rock Island Arsenal*, Contract No. DACA27-88-C-0002 (June 1989).

ECO SUMMARY FORM

PROCESS CATEGORY: Heat Treating

SPECIFIC PROCESS: Quench and Temper Process for Ferrous Parts at ANAD

DESCRIPTION OF ECO:

Apply Ceramic Coating to Firebrick

Spray-on ceramic coatings can increase the surface emissivity of the refractory surface to above 0.95. The increased radiative transfer resulting from this increased emissivity can yield savings in fuel. Although such savings cannot be accurately quantified, energy savings from this measure are conservatively estimated as 15 percent of burner fuel input.

ASSUMPTIONS:

Energy savings conservatively estimated at 15 percent of burner fuel input.

CALCULATION OF BASELINE ENERGY AND EMISSIONS:

Quench furnace:

1. Consumes 1.4 MBtu/hr (the maximum) for 20 hr/wk x 50 wk/yr = 1000 hr/yr
2. Consumes 1.0 MBtu/hr idling at 1600 °F for 20 hr/wk x 50 wk/yr = 1000 hr/yr
3. Consumes 0.8 MBtu/hr turned down to 1400 °F for 8760 - 2000 = 6760 hr/yr
4. Total energy 7808.0 MBtu/yr (average 0.891 MBtu/hr)

Draw furnace:

1. Consumes 1.4 MBtu/hr (the maximum) for 12 hr/wk x 50 wk/yr = 600 hr/yr
2. Consumes 0.4 MBtu/hr idling at 1000 °F for 92 hr/wk x 50 wk/yr = 4600 hr/yr
3. Consumes 0.1 MBtu/hr turned down to 300 °F for 8760 - 5200 = 3560 hr/yr
4. Total energy 3036.0 MBtu/yr (average 0.347 MBtu/hr)

No information on emissions.

CALCULATION OF ECO ENERGY AND EMISSIONS:

	MBtu/hr (average)		
	Baseline	Savings	New Consumption
Quench	0.891	0.134	0.757
Draw	0.347	0.052	0.295

COST DATA:

Capital Cost: for each furnace—$12,600

Annual O&M Savings: No impact.

Ref.: Campbell Design Group, *Energy Survey of Industrial Facilities, Rock Island Arsenal*, Contract No. DACA27-88-C-0002 (June 1989).

ECO SUMMARY FORM

PROCESS CATEGORY: Heat Treating

SPECIFIC PROCESS: Quench and Temper Process for Ferrous Parts at ANAD

DESCRIPTION OF ECO:
Install Recuperators on Gas-Fired Furnace (No. 1 at Anniston)
The most cost-effective system for capturing some of the waste heat in the exhaust is to install a recuperator to preheat the combustion air. The furnace manufacturer makes recuperators for this furnace for this purpose, which are sold as an option.

ASSUMPTIONS:
Recuperator can recover up to 50 percent of the energy in the hot exhaust gas. Recovery is based on the difference between the ambient air and exhaust gas temperatures, assumed values 75 and 1600 °F, respectively.

CALCULATION OF BASELINE ENERGY AND EMISSIONS:
Quench furnace:

1. Consumes 1.4 MBtu/hr (the maximum) for 20 hr/wk x 50 wk/yr = 1000 hr/yr
2. Consumes 1.0 MBtu/hr idling at 1600 °F for 20 hr/wk x 50 wk/yr = 1000 hr/yr
3. Consumes 0.8 MBtu/hr turned down to 1400 °F for 8760 - 2000 = 6760 hr/yr
4. Total energy 7808.0 MBtu/yr (average 0.891 MBtu/hr)

CALCULATION OF ECO ENERGY AND EMISSIONS:
Gross heating value = 22,800 Btu/lb
Specific weight = 0.044 lb/cu ft gas
Air required for combustion = 9.7 cu ft air/cu ft gas
Constant = 1.08 Btu/hr to raise temperature of 1 cfm of air by 1 °F

(0.891 MBtu/hr/22,800 Btu/lb/0.044 lb/cu ft gas) x 9.7 cu ft air/cu ft gas x (1.08 Btu/hr-cfm-°F/60 min/hr) x (1446-75) °F x 0.5 efficiency = 0.106 MBtu/hr saved

Net heat input = 0.891 - 0.106 = 0.785 MBtu/hr

COST DATA:

Capital Cost: Each recuperator for this furnace (one is needed for each of 6 radiant-tube heaters in the furnace) costs $1,500. The total cost for the recuperation system is then $9,000 plus installation, which might add another $3,000-5,000. Cost put into PEPR: $13,000.
Annual O&M Savings: No impact.

Ref.: 1. Campbell Design Group, *Energy Survey of Industrial Facilities, Rock Island Arsenal*, Contract No. DACA27-88-C-0002 (June 1989).

2. Information from T. Price, Atmosphere Furnace Company, to M. Fraser, SAIC.

ECO SUMMARY FORM

PROCESS CATEGORY: Heat Treating

SPECIFIC PROCESS: Quench and Temper Process for Ferrous Parts at ANAD

DESCRIPTION OF ECO:

Leave the Furnaces Turned Down Two Extra Days per Week if Not Needed

To save energy the two furnaces at Anniston are turned down on weekends, and are turned up to temperature at the beginning of the week. However, the production logs indicate that at the present time these furnaces are not used every day, and when they are used, there may be only one job a day (at 1-2 hours for each furnace). Energy could be saved in these furnaces without incurring any capital cost simply by scheduling their use and bunching batches of parts for treating at the same time or at least on the same day. If insufficient work is anticipated, then the furnaces should be left turned down on the weekend schedule for Monday and Tuesday.

ASSUMPTIONS:

The furnaces are left turned down on their weekend schedules (1400 °F for quench, 300 °F for draw) on Mondays and Tuesdays because they do not appear to be needed for production.

CALCULATION OF BASELINE ENERGY AND EMISSIONS:

Quench furnace:

1. Consumes 1.4 MBtu/hr (the maximum) for 20 hr/wk x 50 wk/yr = 1000 hr/yr
2. Consumes 1.0 MBtu/hr idling at 1600 °F for 20 hr/wk x 50 wk/yr = 1000 hr/yr
3. Consumes 0.8 MBtu/hr turned down to 1400 °F for 8760 - 2000 = 6760 hr/yr
4. Total energy 7808.0 MBtu/yr (average 0.891 MBtu/hr)

Draw furnace:

1. Consumes 1.4 MBtu/hr (the maximum) for 12 hr/wk x 50 wk/yr = 600 hr/yr
2. Consumes 0.4 MBtu/hr idling at 1000 °F for 92 hr/wk x 50 wk/yr = 4600 hr/yr
3. Consumes 0.1 MBtu/hr turned down to 300 °F for 8760 - 5200 = 3560 hr/yr
4. Total energy 3036.0 MBtu/yr (average 0.347 MBtu/hr)

No information on emissions.

CALCULATION OF ECO ENERGY AND EMISSIONS:

Quench furnace:

1. Consumes 1.4 MBtu/hr (the maximum) for 16 hr/wk x 50 wk/yr = 800 hr/yr
2. Consumes 1.0 MBtu/hr idling at 1600 °F for 8 hr/wk x 50 wk/yr = 400 hr/yr
3. Consumes 0.8 MBtu/hr turned down to 1400 °F for 8760 - 1200 = 7560 hr/yr
4. Total energy 7568.0 MBtu/yr (average 0.864 MBtu/hr)

Draw furnace:

1. Consumes 1.4 MBtu/hr (the maximum) for 10 hr/wk x 50 wk/yr = 500 hr/yr

2. Consumes 0.4 MBtu/hr idling at 1000 °F for 46 hr/wk x 50 wk/yr = 2300 hr/yr
3. Consumes 0.1 MBtu/hr turned down to 300 °F for 8760 - 2800 = 5960 hr/yr
4. Total energy 2216.0 MBtu/yr (average 0.253 MBtu/hr)

	MBtu/hr (average)		
	Baseline	Savings	New Consumption
Quench	0.891	0.027	0.864
Draw	0.347	0.094	0.253

COST DATA: **Capital Cost:** $0

Annual O&M Savings: No impact.

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