

ENERGY

CONVERSION

**APPLICATIONS OF
THERMAL ENERGY STORAGE
TO PROCESS HEAT AND WASTE HEAT
RECOVERY IN THE
PRIMARY ALUMINUM INDUSTRY**

FINAL REPORT FOR THE
PERIOD SEPTEMBER 1977 – SEPTEMBER 1978

Lincoln B. Katter
Randel L. Hoskins

Date Published – October 1978

Work Performed Under Contract No. EC-77-C-01-5080

ROCKET RESEARCH COMPANY
YORK CENTER
REDMOND, WA 98052



U. S. DEPARTMENT OF ENERGY

Division of Energy Storage Systems

GEO-HEAT CENTER

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

CONS/5080-1

**APPLICATIONS OF
THERMAL ENERGY STORAGE
TO PROCESS HEAT AND WASTE HEAT
RECOVERY IN THE
PRIMARY ALUMINUM INDUSTRY**

**FINAL REPORT FOR THE
PERIOD SEPTEMBER 1977 – SEPTEMBER 1978**

Lincoln B. Katter
Randel L. Hoskins

**ROCKET RESEARCH COMPANY
YORK CENTER
REDMOND, WA 98052**

Date Published – October 1978

**U. S. DEPARTMENT OF ENERGY
Division of Energy Storage Systems**

Work Performed Under Contract No. EC-77-C-01-5080

GEO-HEAT CENTER

1. Report No. CONS/5080-1		2. Government Accession No.		3. Recipient's Catalog No.											
4. Title and Subtitle Applications of Thermal Energy Storage to Process Heat and Waste Heat Recovery in the Primary Aluminum Industry				5. Report Date November 1978											
				6. Performing Organization Code											
7. Author(s) L. B. Katter and R. L. Hoskins				8. Performing Organization Report No. RRC-78-R-608											
9. Performing Organization Name and Address Rocket Research Company York Center Redmond, Washington 98052				10. Work Unit No.											
				11. Contract or Grant No. EC-77-C-01-5080											
12. Sponsoring Agency Name and Address U. S. Department of Energy Division of Energy Storage Systems Washington, D.C. 20545				13. Type of Report and Period Covered Contractor Report											
				14. Sponsoring Agency Code CONS/5080-1											
15. Supplementary Notes Project Manager, H. W. Hoffman, Heat Transfer/Fluid Mechanics Section, Oak Ridge National Laboratory, Oak Ridge, TN.															
16. Abstract This document presents the results of a study entitled, "Applications of Thermal Energy Storage to Process Heat and Waste Heat Recovery in the Primary Aluminum Industry". Work was performed under Contract Number EC-77-01-5080 by a team composed of Rocket Research Company and Intalco Aluminum Corporation, with assistance from Intalco's energy supplier, the Bonneville Power Administration. In this preliminary study, a system has been identified by which the large amounts of low-grade waste energy in the primary pollution control system gas stream can be utilized for comfort heating in nearby communities. Energy is stored in the form of hot water, contained in conventional, insulated steel tanks, enabling a more efficient utilization of the constant energy source by the cyclical energy demand. Less expensive energy storage means (heated ponds, aquifers), when they become fully characterized, will allow even more cost-competitive systems. Extensive design tradeoff studies have been performed for the example site, Intalco Aluminum Corporation and the surrounding communities of Ferndale and Bellingham, Washington. These tradeoff studies indicate that a heating demand equivalent to 12,000 single-family residences can be supplied by the energy from the Intalco site. Using a 30-year payback criterion (consistent with utility planning practice), the average cost of energy supplied over the system useful life is predicted at one-third the average cost of fossil fuel. The exact distribution of this difference between savings to the customers and profit to the utility is not within the scope of this engineering study; however, the study clearly shows that the utilization of waste energy from aluminum plants is both technically and economically attractive. Other economic indices for the 12,000 user case are: <table border="0" style="width: 100%;"> <tr> <td style="padding-right: 20px;">Net capital outlay</td> <td style="text-align: right;">$\\$6.33 \times 10^7$ (1977 dollars)</td> </tr> <tr> <td>Net present value</td> <td style="text-align: right;">$\\$2.56 \times 10^8$ (1985 dollars)</td> </tr> <tr> <td>Average return on investment</td> <td style="text-align: right;">62.8%</td> </tr> <tr> <td>Internal rate of return</td> <td style="text-align: right;">17.1%</td> </tr> <tr> <td>Net displaced energy</td> <td style="text-align: right;">1.37×10^{12} Btu/year</td> </tr> </table> The program included a detailed survey of all aluminum plants within the United States, allowing the site specific analyses to be extrapolated to a national basis. Should waste heat recovery systems be implemented by 1985, a national yearly savings of 6.5 million barrels of oil can be realized. Analysis indicates that there are no technological barriers associated with the implementation of the waste heat recovery system. Operational and cost functions are based upon existing available equipment for all items except the transmission and distribution piping. Advanced piping material technology is currently under study in Europe, with several materials showing considerable promise. Polymer-lined prestressed concrete pipe (PLPC) has been under test since 1975. The primary concern for this material (i.e., relaxation of the prestressing wires), has been answered favorably, even at temperatures above those considered for this study. Remaining concerns for the longevity of the rubber seals (O-rings) would appear to be solvable by 1985. For these reasons, PLPC has been chosen as the baseline material for this study. Based upon the favorable technical and economic results of the program, additional work leading to a full-scale system demonstration at the Intalco Aluminum site is recommended. This program would be carried out in four phases to prove the overall feasibility of the concept and provide the industry with the necessary data for nation-wide implementation.						Net capital outlay	$\$6.33 \times 10^7$ (1977 dollars)	Net present value	$\$2.56 \times 10^8$ (1985 dollars)	Average return on investment	62.8%	Internal rate of return	17.1%	Net displaced energy	1.37×10^{12} Btu/year
Net capital outlay	$\$6.33 \times 10^7$ (1977 dollars)														
Net present value	$\$2.56 \times 10^8$ (1985 dollars)														
Average return on investment	62.8%														
Internal rate of return	17.1%														
Net displaced energy	1.37×10^{12} Btu/year														
17. Key Words (Suggested by Author(s)) Energy Storage, District Heating			18. Distribution Statement Unclassified - Unlimited STAR Category 44 DOE Category UC-94a												
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages	22. Price										

For sale by the National Technical Information Service, Springfield, Virginia 22161

TABLE OF CONTENTS

Section	Page
ABSTRACT	vii
1.0 INTRODUCTION	1
1.1 General	1
1.2 Aluminum Production Technology	3
2.0 SURVEY OF U.S. ALUMINUM PLANTS FOR RECOVERABLE PROCESS HEAT	13
2.1 Survey Approach	13
2.2 Survey Results	13
3.0 SELECTION OF PROCESS ENERGY RECOVERY APPLICATION AND THERMAL ENERGY STORAGE SYSTEMS – TASK II	25
3.1 Utilization of Recovered Process Energy	25
3.2 Storage System Selection	32
4.0 PLANT OPERATIONAL DATA COLLECTION – TASK III	37
4.1 Electrolytic Reduction Cells/Primary Air Pollution Control System Waste Heat Source	37
5.0 ESTABLISHMENT OF INTERFACE DEFINITION – TASK IV	47
5.1 Governmental Restrictions and Requirements	47
5.2 Plant/System Interface	48
5.3 User/System Interface	50
6.0 SIZING AND PERFORMANCE ANALYSIS – TASK V	55
6.1 Aluminum Plant Waste Heat Recovery/District Heating System – Description and Operation	55
6.2 District Heating System Operating and Sizing Computer Code – DHOPS	58
6.3 Weather and Demand Data	67
6.4 User Density Estimates	77
6.5 Analysis Results	81
7.0 PRELIMINARY DESIGN AND ECONOMICS – TASK VI	87
7.1 Preliminary Design	87
7.2 Economic Analysis	92
8.0 SYSTEM ASSESSMENT AND PHASE II PROGRAM PLAN	101
8.1 Phase II – Pilot Plant Detail Design	101
8.2 Phase III – Fabrication, Assembly, and Test of Pilot Plant	105
8.3 Phase IV – Full-Scale System Design	106
8.4 Phase V – Fabrication, Assembly, and Test of Demonstration System ..	107
9.0 SUMMARY AND CONCLUSIONS	109
APPENDIX A	

LIST OF FIGURES

Figure		Page
1	Cross-Section of Aluminum Reduction Cell	4
2	Generalized Process Flow Diagram	6
3	Collection Hooding on a Center-Work Prebake Cell	7
4	Sidework Prebake Cell	8
5	Isometric View of a Horizontal Stud Soderberg Cell	9
6	Vertical Stud Soderberg Cell	10
7	Intalco Cast House	18
8	U. S. Aluminum Plant Locations	21
9	Plant and Population Center Relative Locations	22
10	Non-HSS Process U.S. Primary Aluminum Plants	23
11	Initial Storage System Capital Cost	33
12	Intalco Plant Layout	38
13	1/14 of One Intalco Potline	39
14	Typical Intalco Bag House	40
15	Air Pollution Equipment on Potlines	41
16	Center 4. 1976 Temperatures From Pots	43
17	Heat Exchanger	44
18	Aerial View of Intalco Baghouse and Outside Fume Collection Ducts	49
19	Domestic Hot Water Heater, to Receive Energy From District Heating System	52
20	District Heating System Flow Schematic	56
21	DHOPS District Heating, Operation and Sizing Computer Code	60
22	Capital Cost Factors, Dollars (1977)	63
23	Economic Analyses	66
24	Hourly Operations Summary	68
25	District Heating Operations Summary	69
26	Comparison of Average and Seasons Selected Typical Heating Degree Hours Vs. Month	71
27	Typical and Extreme Heating Seasons Heating Degree Hours Vs. Month	72
28	Small Commercial Energy Demand Vs. Heating Degrees, 1974 - 1976	74
29	Large Commercial Energy Demand Vs. Heating Degrees	75
30	Residential Energy Demand Vs. Heating Degrees, 1974 - 1976	76
31	Large Commercial, 1/31/50	78
32	Residential 1/31/50	79
33	Small Commercial, 1/31/50	80
34	Effect of Storage Volume on User Energy Cost	83
35	System Cost by Element at Minimum Energy Cost Design	84
36	Net Displaced Energy	85
37	District Heating System Flow Schematic	86
38	Bellingham, Washington Population Density Map	88
39	Overall Bellingham District Heating System Layout	89

LIST OF FIGURES (Concluded)

Figure		Page
40	Preliminary Design Fume Collection Duct Heat Exchanger	93
41	Preliminary Design Fume Collection Duct Heat Exchanger Installation	94
42	Effects of Energy Escalation Rate	96
43	User Energy Cost as a Function of Time	97
44	Comparison of Levelized Energy Cost with Growing Energy Cost	99
45	District Heat System Levelized Energy Cost. 12,000 Residential Users Optimized System Configuration	100
46	Utilization of Reject Heat From Aluminum Smelting	102

LIST OF TABLES

Table		Page
1	Current Trends in Aluminum Production Processes	16
2	Energy In Primary Air Pollution Control System for United States Aluminum Plants in 1977	17
3	Indirect Recoverable Process Energy Rankine Cycle Conversion Intalco Aluminum Plant	27
4	Storage System Evaluation	35
5	Major System Tradoff Variables	59
6	Major Program Assumptions	61
7	Cost Information Reference List Primary Sources	64
8	District Heating System Cost Breakdown	91

ABSTRACT

This document presents the results of a study entitled, "Applications of Thermal Energy Storage to Process Heat and Waste Heat Recovery in the Primary Aluminum Industry". Work was performed under Contract Number EC-77-01-5080 by a team composed of Rocket Research Company and Intalco Aluminum Corporation, with assistance from Intalco's energy supplier, the Bonneville Power Administration.

In this preliminary study, a system has been identified by which the large amounts of low-grade waste energy in the primary pollution control system gas stream can be utilized for comfort heating in nearby communities. Energy is stored in the form of hot water, contained in conventional, insulated steel tanks, enabling a more efficient utilization of the constant energy source by the cyclical energy demand. Less expensive energy storage means (heated ponds, aquifers), when they become fully characterized, will allow even more cost-competitive systems. Extensive design tradeoff studies have been performed for the example site, Intalco Aluminum Corporation and the surrounding communities of Ferndale and Bellingham, Washington. These tradeoff studies indicate that a heating demand equivalent to 12,000 single-family residences can be supplied by the energy from the Intalco site. Using a 30-year payback criterion (consistent with utility planning practice), the average cost of energy supplied over the system useful life is predicted at one-third the average cost of fossil fuel. The exact distribution of this difference between savings to the customers and profit to the utility is not within the scope of this engineering study; however, the study clearly shows that the utilization of waste energy from aluminum plants is both technically and economically attractive. Other economic indices for the 12,000 user case are:

Net capital outlay	$\$6.33 \times 10^7$ (1977 dollars)
Net present value	$\$2.56 \times 10^8$ (1985 dollars)
Average return on investment	62.8%
Internal rate of return	17.1%
Net displaced energy	1.37×10^{12} Btu/year

The program included a detailed survey of all aluminum plants within the United States, allowing the site specific analyses to be extrapolated to a national basis. Should waste heat recovery systems be implemented by 1985, a national yearly savings of 6.5 million barrels of oil can be realized.

Analysis indicates that there are no technological barriers associated with the implementation of the waste heat recovery system. Operational and cost functions are based upon existing available equipment for all items except the transmission and distribution piping. Advanced piping material technology is currently under study in Europe, with several materials showing considerable promise. Polymer-lined prestressed concrete pipe (PLPC) has

been under test since 1975. The primary concern for this material (i.e., relaxation of the prestressing wires), has been answered favorably, even at temperatures above those considered for this study. Remaining concerns for the longevity of the rubber seals (O-rings) would appear to be solvable by 1985. For these reasons, PLPC has been chosen as the baseline material for this study. Based upon the favorable technical and economic results of the program, additional work leading to a full-scale system demonstration at the Intalco Aluminum site is recommended. This program would be carried out in four phases to prove the overall feasibility of the concept and provide the industry with the necessary data for nation-wide implementation.

1.0 INTRODUCTION

1.1 GENERAL

The rapid rise in the price of exported petroleum initiated in 1974 has precipitated an aggressive effort to develop energy conservation techniques in the United States. Many techniques which have formerly been technically feasible, but economically unattractive, deserve reevaluation against a background of rapidly rising energy costs. In many cases, energy is rejected to the ecosphere at an otherwise usable state simply because a use for this energy does not coincide with the time at which the energy is available. The role of energy storage is to hold such energy in a usable state until the demand for it arises.

The primary aluminum smelting industry is a large user of prime (electrical) energy. Its waste energy streams are usually of low grade, but high magnitude. The very large amount of low grade energy from this industry makes it an attractive subject for conservation.

There are few uses for the low grade energy. Many of these are currently not established needs, i.e., one could develop a use, but the use currently does not exist. Large-scale heated greenhouse complexes, heated aquiculture, alcohol distillation (for gasoline augmentation), and enhanced crop production through open field soil warming are possible low grade energy uses which do not currently exist. Space conditioning for human comfort is the only widely established demand for large quantities of low grade energy. This end use is the only one which affords direct and immediate reduction of the national dependence upon imported oil. Comfort conditioning tends to be strongly cyclic in energy demand on a daily and annual basis. Through energy storage, the utilization of the constant energy source by a variable demand is enhanced.

A team composed of Rocket Research Company (RRC) (as prime contractor) supported by Intalco Aluminum Corporation and Bonneville Power Administration has conducted a detailed technical and economic evaluation of the benefits to be derived from application of thermal energy storage techniques to process heat and waste heat recovery in the aluminum industry.

The Intalco Aluminum plant in Ferndale, Washington, has served as a typical aluminum plant for the study described herein. Intalco supplied detailed operational data on the plant and assisted in the evaluation of plant installation and operation variables. Bonneville Power Administration, the supplier of electrical power to the Intalco plant, supported the program economic analyses with data on electrical power rates and availability on both a local and national level.

The program, with the technical effort completed in a 6-month time period, was accomplished in seven tasks as listed below:

- Task I – Literature and Aluminum Industry Survey
- Task II – Process and Storage System Selection
- Task III – Plant Operational Data Collection
- Task IV – Interface Definition
- Task V – System Design Analysis
- Task VI – Preliminary System Design and Cost Analysis
- Task VII – Phase II Program Plan

The program was initiated with a literature and aluminum industry survey. The literature search and survey were aimed at determining the magnitude of potentially recoverable waste energy on a national basis and in assuring that the Intalco Aluminum plant was typical of those in the industry, so that detailed study results obtained with their plant were valid on a nation-wide basis.

Following the national survey, review was made of the aluminum plant waste heat sources. Based on preliminary engineering and economic analyses, the aluminum waste heat source to be utilized for recovery was selected. After selection of the energy source, a selection was made for the application of the waste energy. Task II was completed by the selection of a thermal energy storage system for use with the waste heat recovery system.

During Task III, test measurements were made at the Intalco Aluminum plant to verify the magnitude of and temperature of the waste energy streams.

In Task IV of the program, interface requirements for the waste heat recovery system were finalized. This effort included both the definition of interface requirements within the Intalco plant and those external to the plant.

The major effort on the program occurred in Task V. Under this task, a detailed trade study was conducted to arrive at a system design approach which represented an optimum utilization of the waste heat from the Intalco plant (both from technical and economic viewpoints).

In Task VI, a preliminary design was completed of the waste heat recovery system, and preliminary cost analyses were conducted to determine the capital cost of installing the system.

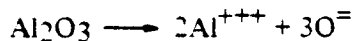
The program was completed in Task VII by preparing recommendations for additional work and in writing a preliminary program plan for the next phase of work.

1.2 ALUMINUM PRODUCTION TECHNOLOGY

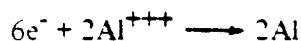
1.2.1 Hall-Heroult Process

The only large-scale aluminum reduction process currently in use in the world is the Hall-Heroult process. This process produces aluminum by electrolytically reducing alumina (Al_2O_3) in a molten bath of cryolite as shown below.

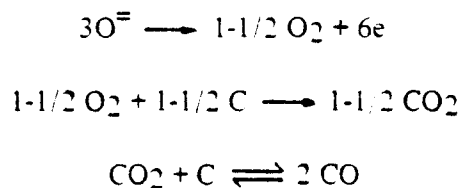
In the molten cryolite, the alumina ionizes to:



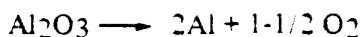
As electrons flow through the molten cryolite, aluminum metal is formed at the cathode (negative electrode):



At the anode (positive electrode), oxygen is produced and reacts with the carbon anodes forming carbon dioxide and carbon monoxide:



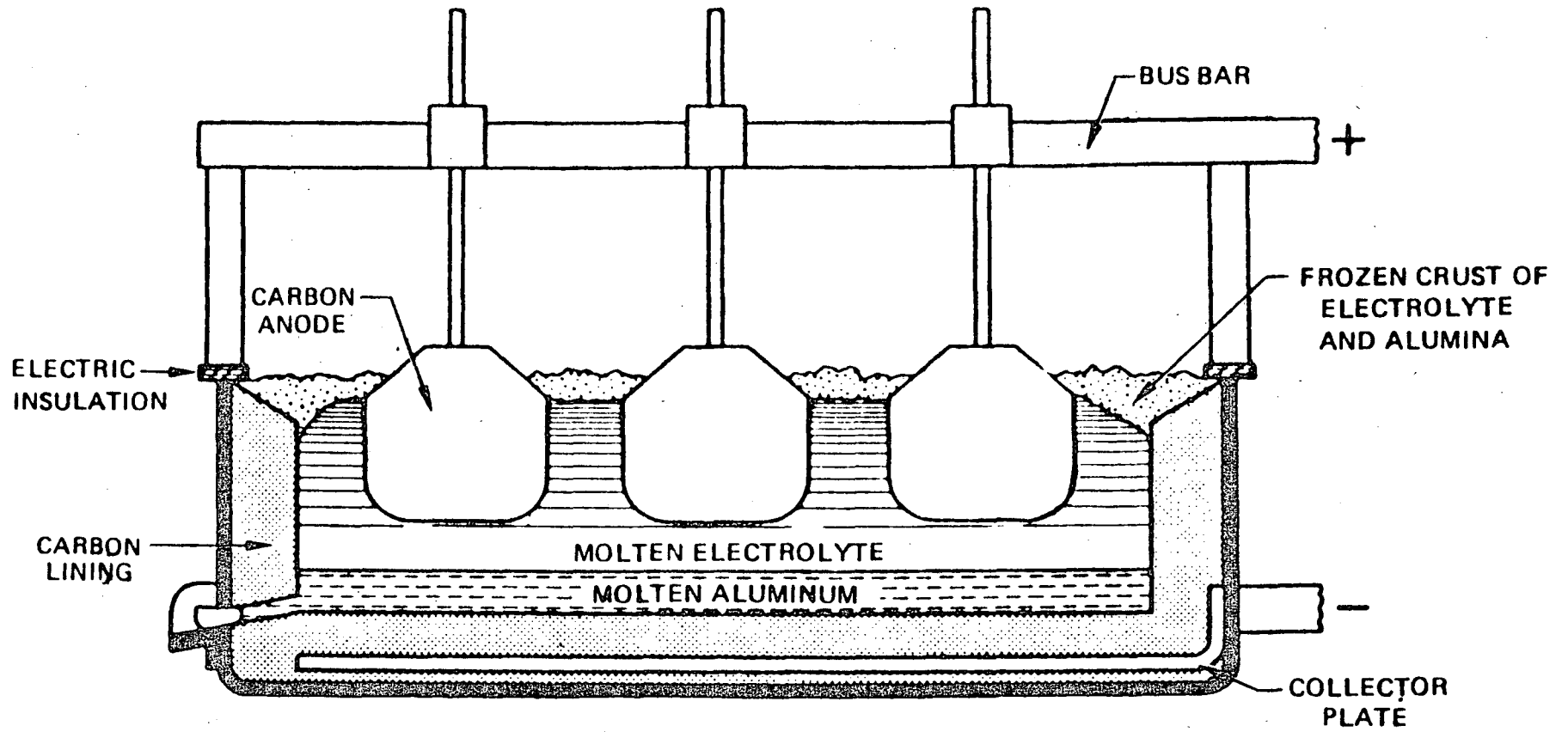
The basic reaction:



theoretically requires 3.90 Kw-hr/lb of aluminum produced. In actual practice, however, additional energy is consumed and ultimately lost in the sensible heat of the products, lost due to nonproductive side reactions (production of HF and cryolite-rich volatiles), and lost in electrical resistances within the reduction bath and in the electrical conductors. For the United States' aluminum industry, the electrical energy requirements are typically 6.1 to 8.2 Kw-hr/lb of aluminum produced. The vast majority (over 90%) of the difference between the theoretical reaction energy and the actual energy used to drive the reduction process appears as thermal energy. This thermal energy and the additional thermal energy evolved by the carbon-oxygen secondary reaction (totaling 12,900 to 19,400 Btu/lb of aluminum) must be removed from the bath during the reduction process to maintain the bath heat balance.

The electrolytic cells (commonly called pots in the aluminum industry) used to reduce the alumina to aluminum are similar to the cell shown in Figure 1. The cells may be up to 30 feet long and 15 feet wide, depending upon the exact type of cell and the production rate

CROSS-SECTION OF ALUMINUM REDUCTION CELL



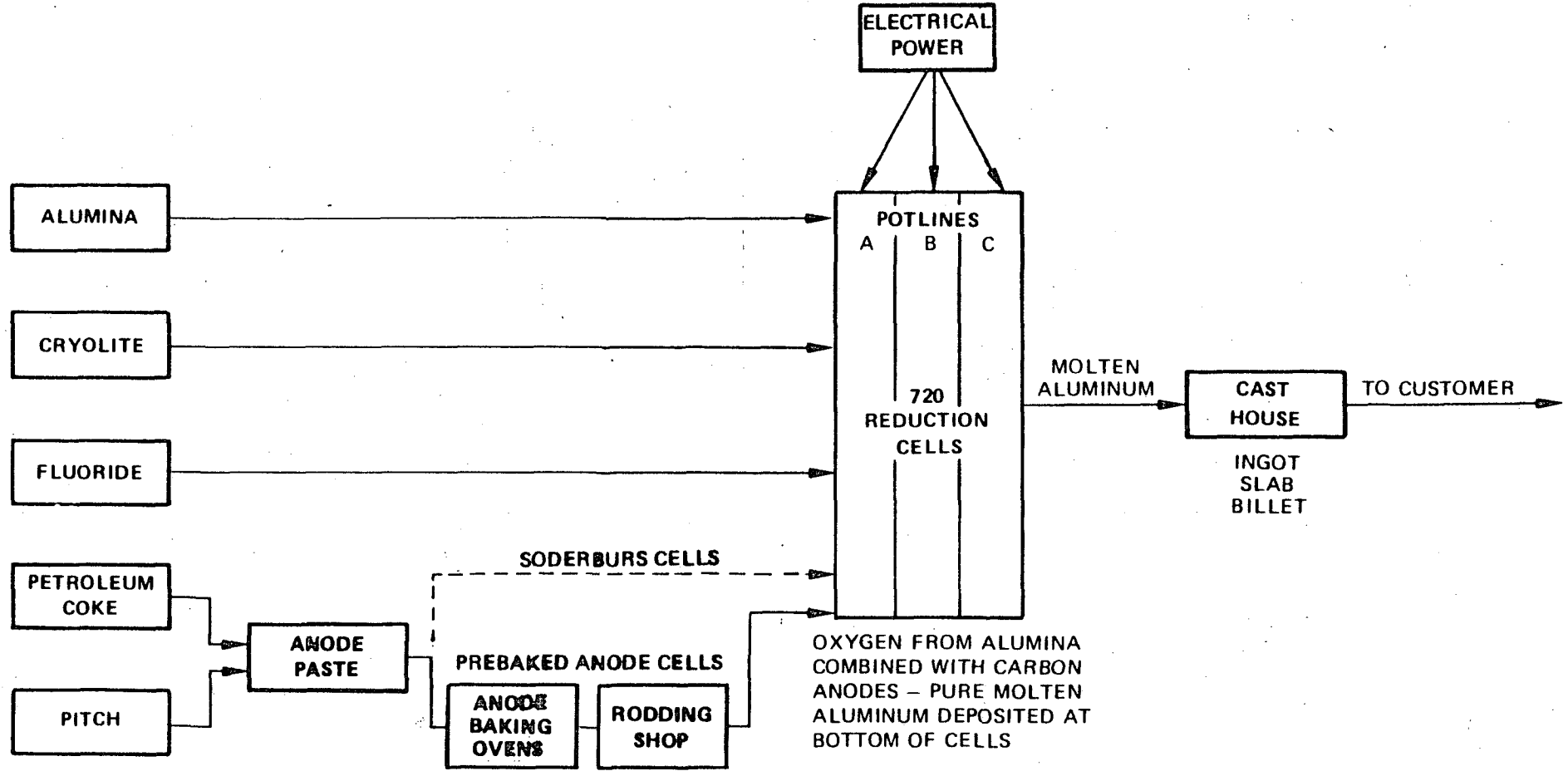
for which the cell is designed. The individual electrolytic cells are electrically connected in series, forming groups of cells called potlines. Each potline may contain up to 240 cells. In each cell, alumina dissolved in the molten cryolite is reduced electrolytically to molten metallic aluminum which in turn serves as the cathode. As the carbon anodes are oxidized by the liberated oxygen, the anodes are adjusted down or replaced as necessary. At intervals, molten aluminum is tapped from the cells, transported to a casting facility, where it is alloyed (if desired), cast into ingots or billets, and cooled. As required by the cell, additional alumina and fluorides are dissolved into the molten cryolite. The fluorides are required to maintain the proper cell chemistry. A generalized process flow diagram is presented in Figure 2.

Electrolytic Reduction Cell Types – There are two basic types of cells used in the Hall-Heroult process – those with multiple, prebaked anodes, and those with a self-baking or Soderberg anode. In both types of cells, the anodes are suspended from a superstructure extending over the cell such that the vertical position of the anodes may be adjusted as the anodes are consumed during the reduction process. In a prebake cell, the anodes are formed from a coke/coal tar pitch mixture and baked (to approximately 2,100°F) in an oven prior to being used in the reduction cell. As the prebake anodes are consumed, the anode butts are removed and new anodes added. In a Soderberg cell, the coke/coal tar pitch mixture is loaded into a steel frame on top of the reduction cell and baked by the heat coming from the top of the cell and electrical resistance. As the anode is consumed from the bottom, the anode is lowered; and more of the coke/coal tar pitch mixture is added to the top of the anode.

The prebaked anode cells are further broken down into two subtypes – center-worked prebake cells (CWPB) and side-worked prebake cells (SWPB). The center- and side-worked designations refer to where the alumina is added to the cell. Where required by air pollution control agencies (currently at all but one U.S. primary aluminum plant), the pots are covered with metal hoods to collect the evolved gases and dust particles. The hoods are ducted together, and the hood exhaust gases transported to scrubbers where the dust and fluorides are removed and the gases vented to the atmosphere. The hoods and the scrubbing system are called the primary air pollution control system. A typical hooded CWPB pot is shown in Figure 3. Figure 4 shows a typical SWPB pot. The SWPB pot shown in Figure 4 has one of the hood doors open as would be required for pot tending operation (adding alumina, changing anodes, etc.).

Soderberg cells are also broken down into two subtypes – horizontal stud Soderberg (HSS), and vertical stud Soderberg (VSS), shown in Figures 5 and 6, respectively. In a VSS cell, the electrical current carrying studs project vertically through the unbaked paste portion and into the baked portion of the anode. In an HSS cell, the current carrying studs are inserted nearly horizontally into the anode. As the anode is lowered to replace the consumed carbon, studs must be extracted and reset to higher positions. Since both types of Soderberg cells have a single anode in the center of the cell, all cell tending operations are around the side of the anode.

GENERALIZED PROCESS FLOW DIAGRAM

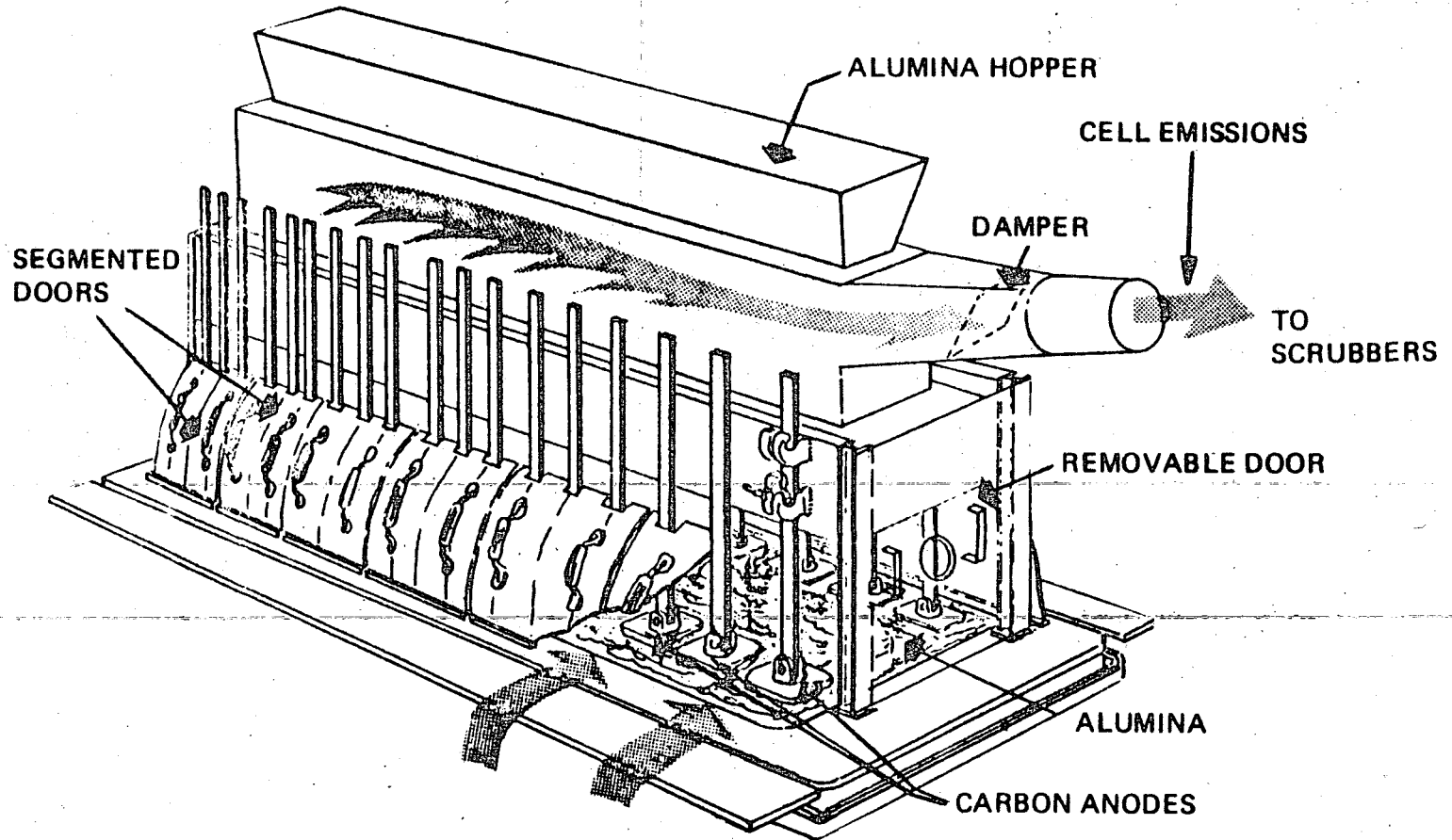


29007-95A

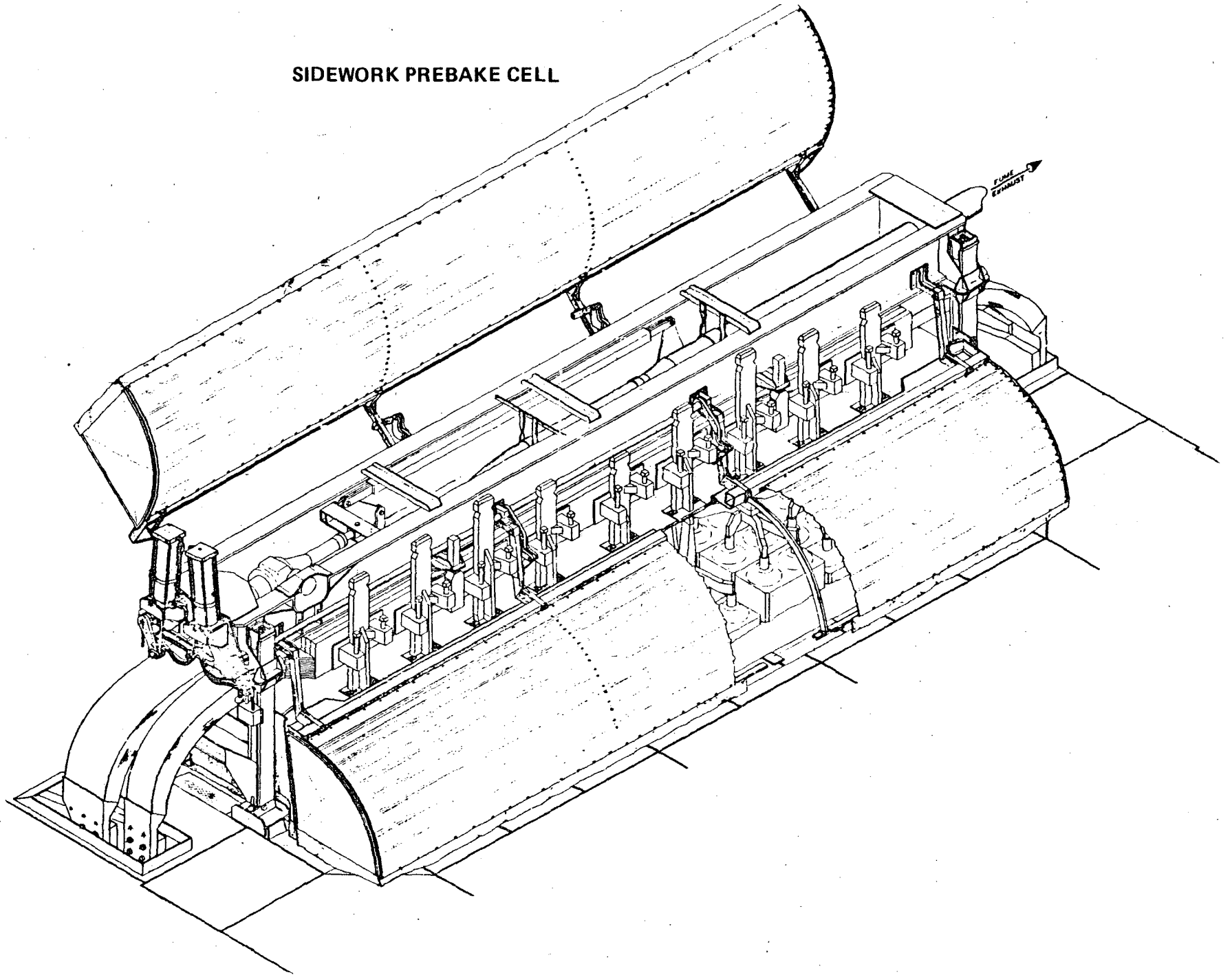
6

Figure 2

COLLECTION HOODING ON A CENTER-WORK PREBAKE CELL



SIDEWORK PREBAKE CELL

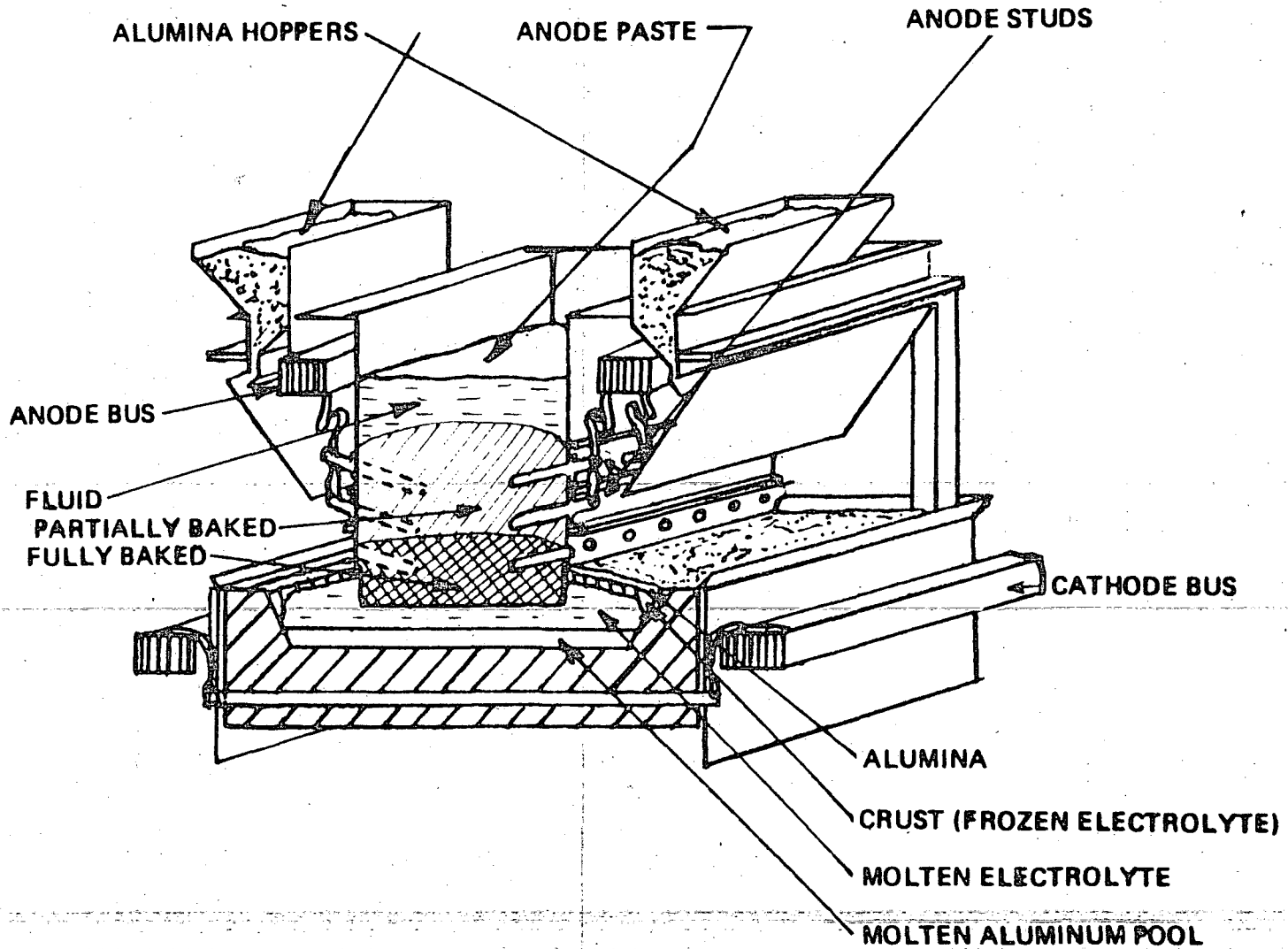


29014-86

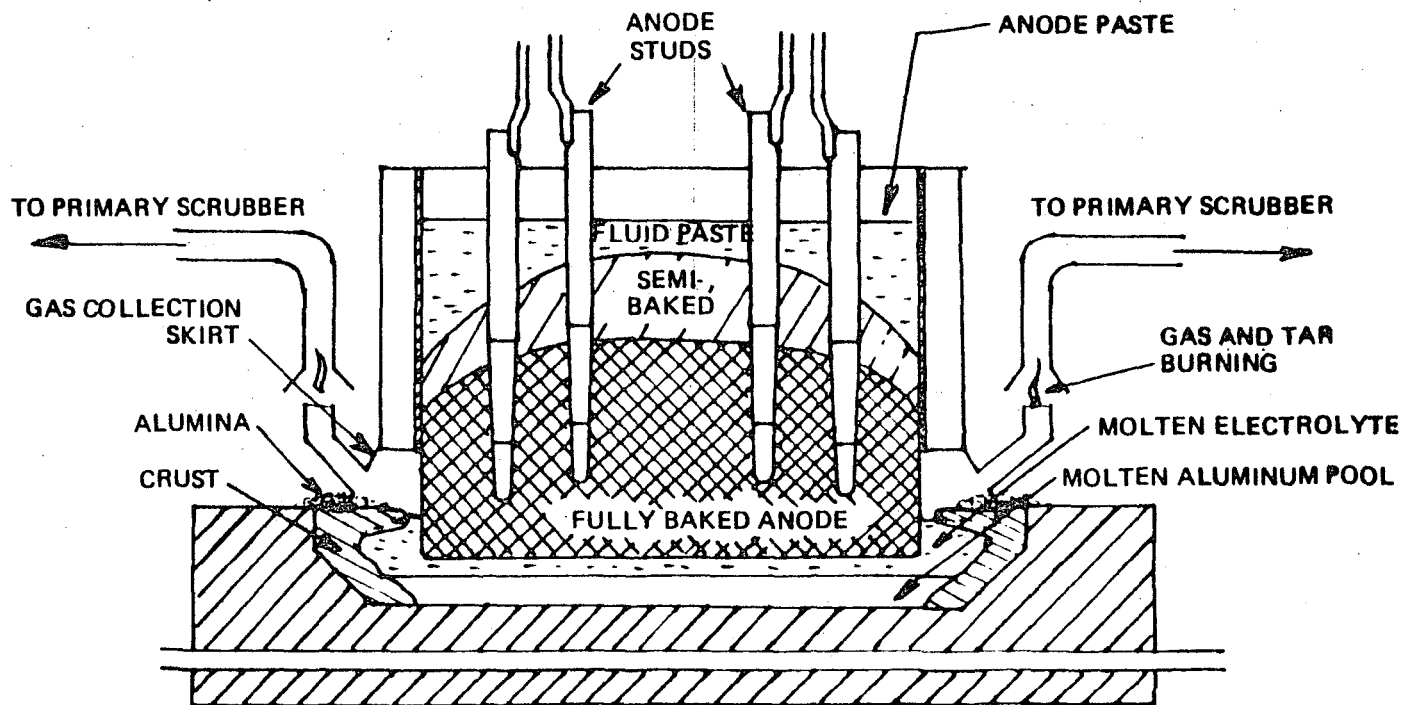
8

Figure 4

ISOMETRIC VIEW OF A HORIZONTAL STUD SODERBERG CELL



VERTICAL STUD SODERBERG CELL



Since the Soderberg anode is baked in conjunction with the reduction process, the hydrocarbons and volatiles released from the baking pitch binder are added to the cell gas and dust emissions associated with the reduction process. The pitch binder emissions have a tar-like nature. Since the anode studs on VSS cells are located above the cell superstructure, VSS cells have an integral gas collection skirt around the cell casing. This enables the tar and gas emissions to be collected at a sufficient concentration and temperature to maintain combustion of the products in special burners adjacent to the cells as shown in Figure 6. These burners essentially completely burn up the tar-like hydrocarbons and volatiles.

HSS cells do not use the same integral gas collection skirt and burner arrangement as the VSS cells. Since the anode casing for an HSS cell has removable sections for repositioning the horizontal stud as shown in Figure 6, the removable sections do not permit installation of an integral gas collection skirt. Because of this, collection is accomplished by hooding with removable side panels (to allow access for cell tending operations). This form of collection results in air dilution to such an extent that self-combustion of the released tars and gases in the burner is not possible. Typically, these tars are removed by wet-scrubbing.

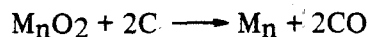
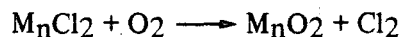
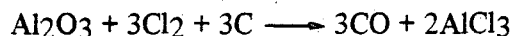
1.2.2 Alternate Aluminum Production Technologies

While the Hall-Heroult process is the only large-scale primary aluminum production process currently being used in the world, there are a number of other alternative primary aluminum production processes that have been considered since the Hall-Heroult process was first developed in 1886. None of the alternative processes described below have reached the point where they can economically compete with Hall-Heroult process. All of the large primary aluminum plants being constructed or proposed are Hall-Heroult plants. The major alternative processes under current consideration are:

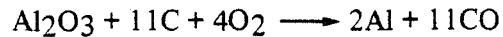
1. Tolt process
2. Alcoa silicon/aluminum alloy process
3. Alcoa $AlCl_3$ electrolytic reduction process

These three process are described in more detail in the following paragraphs.

Tolt Process – The Tolt process is a multistep, nonelectrolytic process which uses carbon in the form of coke to reduce alumina via an $AlCl_3$ intermediate stage. The basic reactions are shown below:



Since the chlorine and manganese are recycled with the process, the net reaction with alumina is:



Because the Tolt process is in an early stage of development, no real plant operating process parameters are available. The high carbon consumption required for the process appears, however, to offset any cost savings over the Hall-Heroult process. Based upon a preliminary evaluation of the process, there appears to be a number of high and low grade waste heat streams that could be recovered from within the process.

Alcoa Silicon/Aluminum Alloy Process – The Alcoa silicon/aluminum alloy process is direct reduction process which produces an aluminum/silicon alloy by reducing the ores with carbon (cool) in furnaces similar to iron and steel blast furnaces. The process produces as a by-product 16 times as much CO as aluminum. Preliminary cost analyses performed by Alcoa indicate that the process is only viable if the CO by-product gases can be sold to an outside user.

The Alcoa silicon/aluminum alloy process is still at the lab-scale development stage. A joint DOE/Alcoa research program on the process is underway to construct a small-scale pilot unit to determine the feasibility of the concept.

Alcoa AlCl₃ Process – The Alcoa AlCl₃ process is a proprietary electrolytic process involving the reduction of AlCl₃ at 1,400°F in closed cells. The evolved Cl₂ gas is recycled within the process and is used in conjunction with carbon to produce AlCl₃ from alumina (Al₂O₃). The AlCl₃ process is claimed by Alcoa to reduce the electrical energy requirements by 30% over the Hall-Heroult process plants. Much of the electrical cost savings appear to be offset by additional carbon (cool) required to produce the aluminum chloride.

While Alcoa is currently testing the process on a pilot plant level (nominal 15,000 tons/year) at Palestine, Texas, in an effort to reduce the process to commercial practice, there is currently much discussion in the primary aluminum industry as to how practical and efficient the process will be when and if it is reduced to commercial practice.

2.0 SURVEY OF U.S. ALUMINUM PLANTS FOR RECOVERABLE PROCESS HEAT

The baseline district heating waste heat recovery concept was based upon a study of the Intalco Aluminum Corporation and appropriate primary aluminum production literature. The purpose of the Task I waste heat survey was to review the primary aluminum industry with regards to potentially recoverable thermal process energy sources and applications for the recovered energy. This information was then be used to develop a data base to ensure that the baseline district heating system, or an alternative waste heat recovery concept to be selected in Task II, would be applicable to the primary aluminum industry as a whole.

2.1 SURVEY APPROACH

The Task I survey efforts consisted of three separate parts:

1. Literature survey
2. Waste heat questionnaire
3. Plant visits

The literature review was aimed at determining trends in primary aluminum production technology and appropriate waste heat recovery technology.

Waste heat survey questionnaires were mailed to each of the primary aluminum producers in the United States. A copy of the survey form and the standard cover letter are presented in Appendix A. Prior to mailing out the waste heat survey forms, each of the producers was contacted by telephone, and contacts were made with the appropriate people in each organization. As the surveys were returned, follow-up calls were made as required to the various plant personnel to further clarify the supplied data.

During the course of the program, three primary aluminum plants in addition to the Intalco Aluminum Plant were visited by program personnel and discussions held with plant personnel on both the various waste heat recovery/utilization concepts and on potential plant-related problems. The plants visited were typical of the entire range of Hall-Heroult process aluminum production electrolytic reduction cell types used in the United States. The three plants visited were the Reynolds Aluminum plants at Troutdale, Oregon (CWPB cell plant); Longview, Washington (HSS cell plant); and the Martin Marietta Aluminum plant at Dalles, Oregon (VSS cell plant). The Intalco Aluminum Corporation plant is a SWPB cell plant.

2.2 SURVEY RESULTS

Waste heat survey information was received from 29 out of the 31 United States primary aluminum plants. The plants supplying information correspond to approximately 97% of the total U.S. aluminum production capacity. Some of the information requested (primarily

related to current production rates and energy consumption) on the survey forms was felt to be proprietary by some of the aluminum producers and was not supplied by them. Where this data was required for the analysis efforts, the required data was estimated, based upon similar type plants and alternative information sources.

2.2.1 Waste Heat Sources

The major waste heat sources in primary aluminum industry are the cast house, anode baking ovens (prebaked anode cell plants), and the electrolytic reduction cells. Each of these waste heat sources is described in more detail in the following sections.

Electrolytic Reduction Cells – The electrolytic reduction cells consume approximately 80% of the energy used in the primary aluminum plants. This figure includes the fuel value of the carbon consumed in the anodes. Considering only the energy used directly in the plant, i.e., natural gas, fuel, and electricity, the reduction cells account for over 90% of the energy consumed within the plants.

While the exact percentage varies widely from plant to plant, approximately 50% of the total energy input to the reduction cells is converted to thermal energy and must be removed from cell to maintain the proper cell operating temperature. Much of this energy is picked up along with the air and pot gases by the primary air pollution control system with the remaining energy radiated and convected into the potroom environment. In plants which in the past have not had primary air pollution control systems, all of the energy was transferred to the potroom environment (currently all but one of the U.S. primary aluminum plants have or are installing primary air pollution control systems). The one remaining plant will be installing a primary air pollution control system within the next few years to meet Federal air pollution control requirements.

The gas temperature and the amount of energy entrained in the primary air pollution control system gases varies, depending upon the cell type and the plant operating parameters. The approximate gas temperature range for each type of cell is listed below:

SWPB	250 to 290°F
CWPB	185 to 300°F
VSS	400 to 700°F
HSS	195 to 300°F

From a heat recovery standpoint, both types of prebaked anode cells are essentially identical in approximate primary air pollution control system gas temperature and flow rates (per ton of metal produced). The gases in the primary air pollution control system in both types of cell consist primarily of air, cell gas emission (pot gases), and contain a slight amount of particles and cryolite.

The gas flow rates and temperature of the primary air pollution gas stream from HSS cells are basically the same as from the prebaked anode cells, except that gases coming off the

HSS cells are very heavily laden with soot and hydrocarbon tars produced by the baking anode paste. As long as the gas temperature remains fairly high, these tars tend to remain in suspension. When these gases are cooled, the tars condense out. These tars would tend to build up on any heat exchanger surfaces at a high rate (more than 0.9 inch/week). Thus, in HSS plants, any heat recovery heat exchangers in the primary air pollution control system, would require heat exchangers employing effective surface cleaning methods.

In VSS plants, the soot and hydrocarbon tars in the gases are burned as they leave the cells and do not enter the primary air pollution control system, eliminating any problems with tars building up on the heat exchangers. VSS cells typically tend to dump greater percentage of the waste heat from the cells into the potroom environment, resulting in less thermal energy being picked up by the primary air pollution control system. The lower quantity of thermal energy in VSS plants is somewhat effected by the higher temperature (400 to 700°F) of the primary air pollution control system gases which increases the availability of the energy.

While the relative merits of the various cell types are not generally agreed upon by the industry, the trend in the United State and Europe for new production capability is toward prebaked anode cell plants. This trend is shown in Table 1.

The total quantities of energy potentially recoverable from each of the U.S. primary aluminum plant fume collection systems are presented in Table 2. This amount of energy (7.39×10^9 Btu/hr) corresponds to approximately 83.5% of the recoverable energy from the three primary waste heat sources.

Cast Houses – At regular intervals, molten aluminum (1,800°F) is removed from the cells and transferred to holding furnaces in the cast house. The interior of a typical cast house (Intalco) is shown in Figure 7. In the holding furnaces, the metal is alloyed, stirred, and prepared for casting. The metal is held during this process at a casting temperature of 1,300 to 1,400°F until it is cast into the required form. Typically, the aluminum is cast in a water cooled mold. Some of the cast aluminum forms (typically extrusion billets) go through a heat treating process called homogenizing before leaving the cast house. In this process, the cast aluminum pieces are placed in special homogenizing furnaces and held at a temperature of 1,000 to 1,100°F for a period of 4 to 8 hours.

Cast houses typically have two supporting operations – a dross reclamation facility and a remelt furnace. The dross operation involves the recovery of molten metal from dross. Dross is a combination of aluminum oxide, alloy oxides, and aluminum metal which is skimmed from the furnaces prior to casting. This material is transferred to a rotary kiln and processed with salt at approximately 1,400°F. The oxides and the salt form a slag material, and the metal separates and is recovered. The remelt furnace operation is comprised of a melting furnace which is charged with recycled scrap, saw chips, and the metal from the dross operation. Occasionally, for special alloying needs, precast bar is also charged. This metal is melted down, tapped into a metal transfer ladle, and transported to one of the holding furnaces where it is converted into product along with the metal from the potlines.

Table 1
**CURRENT TRENDS IN ALUMINUM
 PRODUCTION PROCESSES**

	<u>Pre-Bake Number of Plants</u>	<u>Plant Expansions</u>	<u>HSS Number Plants</u>	<u>Plant Expansions</u>	<u>VSS Number of Plants</u>	<u>Plant Expansions</u>
1973	20	—	7*	—	4	—
1974	20	—	7	—	4	—
1975	20	4	7	—	4	1
1976	20	6	7	—	4	—
1977	20	2	7	—	4	—
1978	20	1	7	—	4	—
1979	20	1	7	—	4	—
1980	20	2	7	—	4	—
1980 Production Capacity	3.767 x 10 ⁶ tons/year		1.043 x 10 ⁶ tons/year		0.613 x 10 ⁶ tons/year	
% of Total 1980 Production Capacity	69.5		19.2		11.3	

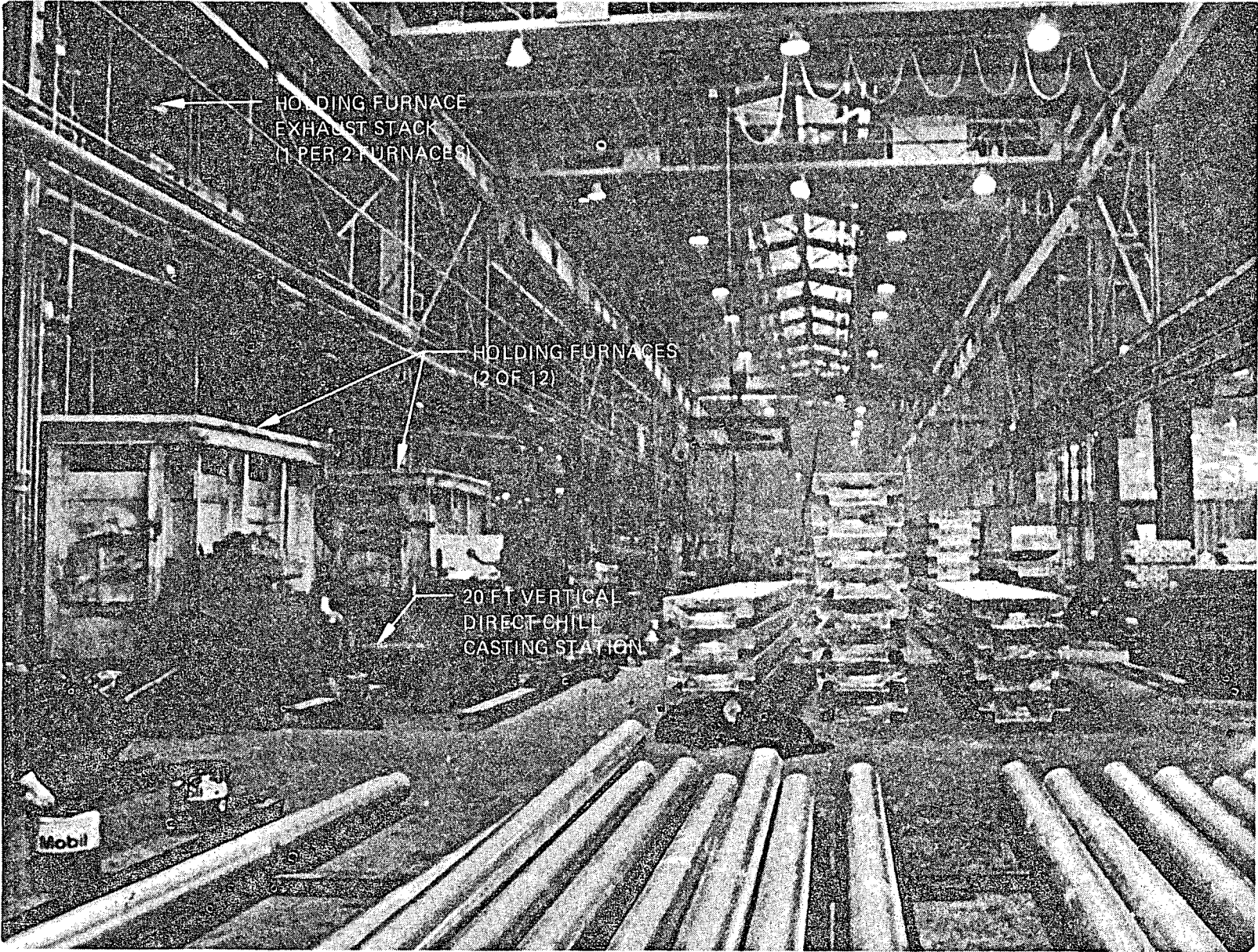
Table 2
ENERGY IN PRIMARY AIR POLLUTION CONTROL SYSTEM FOR
UNITED STATES ALUMINUM PLANTS IN 1977

<u>Company</u>	<u>Location</u>	<u>Fume Temp. (°F)</u>	<u>Fume Energy Above 70°F</u>	<u>Cell Type</u>
Alcoa	Evansville, Indiana	260	344.4 x 10 ⁶	CWPB
	Massena, New York	260	255.3	CWPB
	Badin, North Carolina	260	148.4	CWPB
	Alcoa, Tennessee	260	255.3	Comb
	Point Comfort, Texas	260	219.7	VSS
	Rockdale, Texas	260	368.1	CWPB
	Vancouver, Washington	260	136.6	CWPB
	Wenatchee, Washington	260	243.4	CWPB
Anaconda	Sebree, Kentucky	200 *	216 *	CWPB
	Columbia Falls, Montana	700	130	VSS
Consolidated	Lake Charles, Louisiana	286	56	SWPB
	New Johnsonville, Tennessee	286 *	191 *	SWPB
Eastalco	Frederick, Maryland	260	186	SWPB
Intalco	Ferndale, Washington	260	317	SWPB
Kaiser	Chalmette, Louisiana	255	592	HSS
	Mead, Washington	190	239	CWPB
	Tacoma, Washington	255 *	230 *	HSS
	Ravenswood, West Virginia	185	205	CWPB
Martin-Marietta	The Dalles, Oregon	400	36	VSS
	Goldendale, Washington	400	67	VSS
National Southwire	Hawesville, Kentucky	240	260	CWPB
Noranda	New Madrid, Missouri	240 *	182 *	CWPB
Ormet	Hannibal, Ohio	300	498	CWPB
Revere	Scottsboro, Alabama	NA		SWPB
Reynolds	Listerhill (Sheffield), Alabama	195	373	HSS
	Arkadelphia, Arkansas	250	184.8	Comb
	Jones Mills, Arkansas	215	237.1	CWPB
	Massena, New York	200	282	HSS
	Troutdale, Oregon	215	246	CWPB
	Corpus Christi, Texas	200 *	313 *	HSS
	Longview, Washington	225	378	HSS
			7,392 x 10 ⁶ Btu/hr	

*Estimated from data of similar plant

03072-2 R1

INTALCO CAST HOUSE



29008-19

18

Figure 7

The waste process energy from the cast house operations consists primarily of energy in the stack gases of the various furnaces and as the latent and sensible energy of the aluminum given off during the casting process. The temperature of the stack gases off the holding, dross, homogenizing, and remelt furnaces ranges from 265 to 1,800°F. The lower gas temperatures are the result of cooling or being mixed with the furnace gases in the stacks to prevent damage to the stacks by the hot furnace gases. Due to the nature of the water chill casting process used by most of the plants, the energy produced by the cooling aluminum during the casting process appears as a rise in the mold cooling water temperature with the maximum temperature below 150°F.

The total energy consumed by the cast house is only about 4% of that consumed by the plant. Assuming all of the furnace stack gas energy could be recovered before it was mixed with cooling air in the stacks, the total amount of recoverable energy from the furnaces would amount to approximately 10.5% of the potentially recoverable energy from the three primary waste heat sources.

Anode Baking Furnace – All but one of the United States' prebake plants have anode baking ovens. The one prebake plant without an anode baking furnace purchases its baked anodes from a nearby sister plant.

The majority of plants use ring furnaces, which are sunken baking pits with interconnecting flues to bake the green anodes. The baking pits are fired with natural gas or oil. The flue system in the baking permits the hot gases from the sections of the pits being fired to preheat the next batch of anodes to be baked.

Another type of bake furnace called a tunnel kiln is also used. In a tunnel kiln, the anodes are baked under a controlled atmosphere (to prevent oxidation of the anodes) in a long kiln. The flue gases from each type of furnace are heavily laden with tars, soot, and particulate matter generated during the baking process and must be wet scrubbed before being released to the atmosphere. The average temperature of the anode baking furnace exhaust gases is approximately 375°F before the scrubbers.

For the industry as a whole, anode baking furnaces consume only about 3.6% of the energy used for primary aluminum production and contain only about 6.0% of the potentially recoverable energy from the three primary waste heat sources.

Other Sources – In addition to the three primary waste heat sources, some primary aluminum plants have additional major waste heat sources. Four United States aluminum plants generate their own electrical power with on-site thermal electric generators. These generators represent potential waste heat recovery sources from their stack gases and condensers (turbines operated in back-pressure mode for cogeneration applications). At least one aluminum plant has an on-site coke calciner. The coke calciner represents a waste heat source at approximately 2,000°F.

2.2.2 Plant Locations

The 31 United States primary aluminum plants are located throughout the country as shown in Figure 8. The plants tend to be located near sources of low-cost electrical power.

For external utilization applications of the recovered waste heat, the distance that the energy must be transported from the plant to the point of use determines whether or not the energy can be utilized economically. For the baseline district heating system, the required transport distance is the distance from the plant to the nearby population centers. Figure 9 shows the relative plant and population center distances for the United States primary aluminum plants. The same information with the HSS process plants eliminated is shown in Figure 10 (leaving approximately 80% of the United States production capacity).

It should be noted, however, that even where the thermal energy transport distances may be too great to be economical, a district heating system or other external utilization application may still be practical. Given the availability of low-cost thermal energy to the area surrounding each aluminum plant, it is conceivable that potential users would tend to locate in an area close to the plant. The strongest attraction would be to industrial operations with a large demand for low-grade thermal energy, i.e., a very concentrated demand by comparison to the example site chosen for this study. Such situations would be expected to show even better economic criteria than the example case. The aluminum plant, by offering low-cost energy, could in essence create a demand for that energy over time.

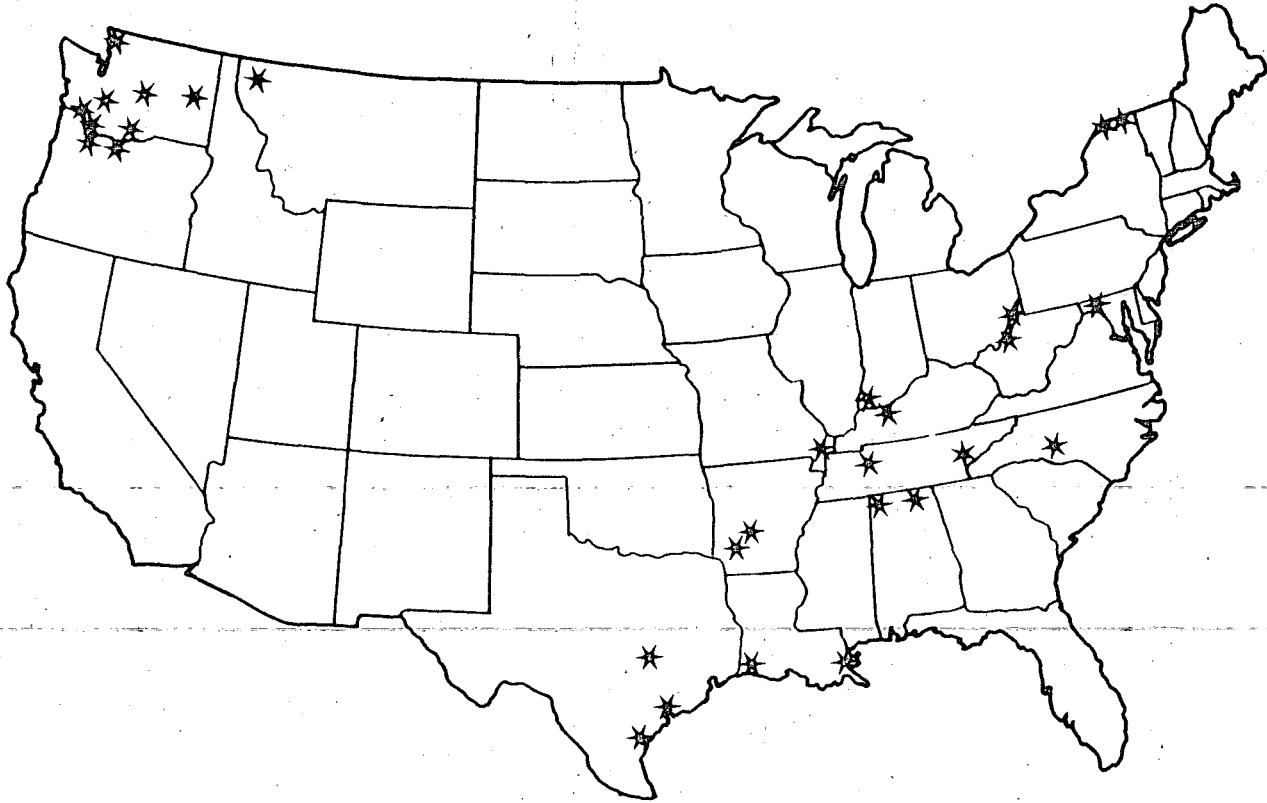
2.2.3 Predicted Trends

The search for defined trends in the aluminum industry was made so that the magnitude of the waste energy streams could be predicted for the 1985 time frame. References 1 and 2 list data on past and/or near future primary aluminum production capability in the United States. As is evident from the data of Table 1, there have been no new primary aluminum plants built in recent years. Two new plants are under consideration at the current time. Environmental concerns have delayed the ground breaking for the more advanced of the two proposals. Taking a conservative estimate, it is assumed that neither plant will be operational by 1985.

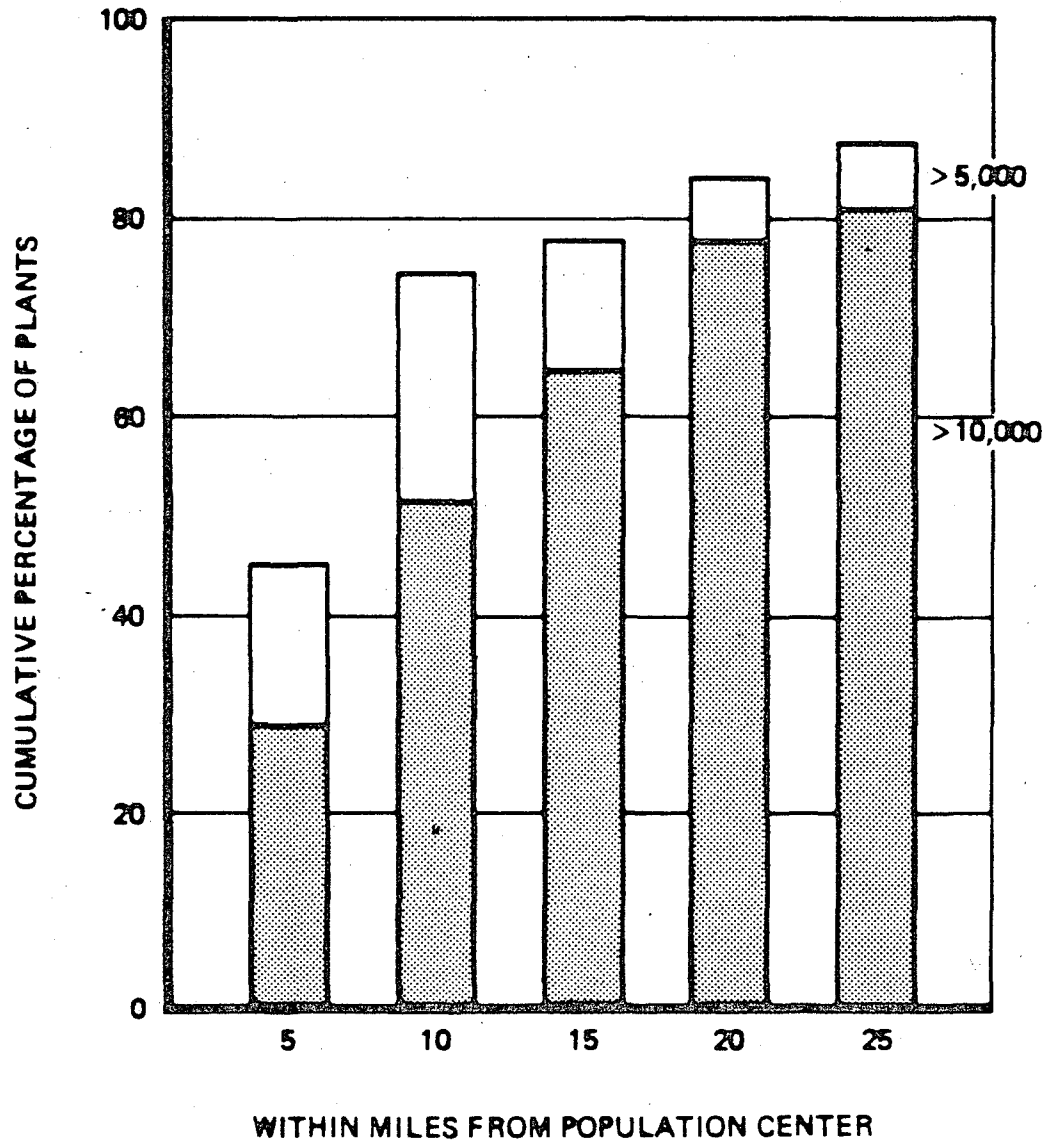
Thus, the trend set for the last several years is likely to continue; expansion in primary aluminum smelting capacity will be through expanded capability at existing plants. In the past, the rate of expansion has been between 1 and 1.7% per year. It is concluded that aluminum production capability in 1985 will exceed that of 1977 by 8 to 14%. An increase of 11% for this same period has been assumed in this analysis. As the total energy in the fume streams is, at least to the first approximation, directly related to the primary

-
- 1) *Aluminum Statistical Review*, The Aluminum Association, Inc., 1976
 - 2) *Primary Aluminum Plants, Worldwide*, Part 1, Detail, Bureau of Mines, Division of Nonferrous Metals, June 30, 1977

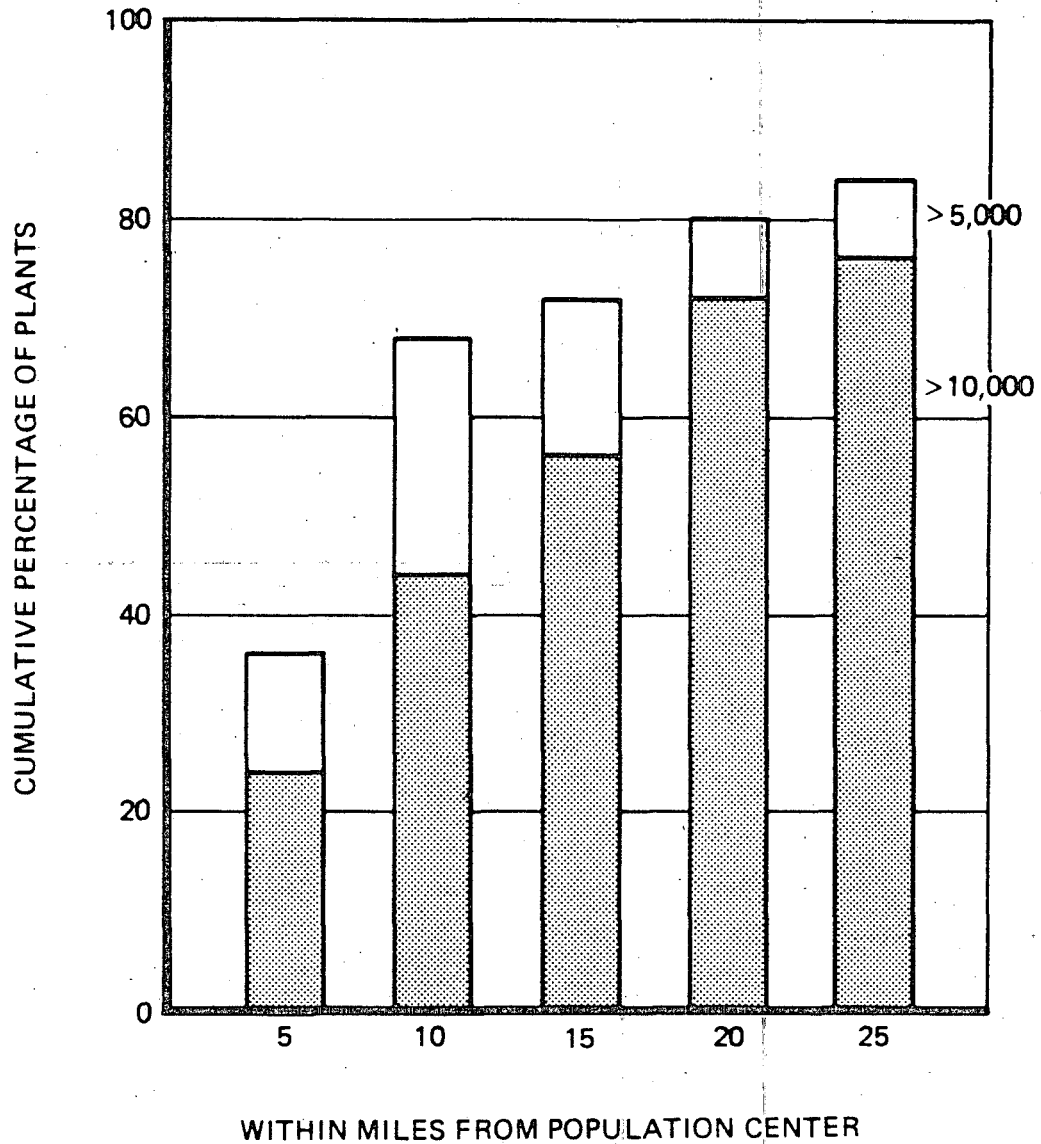
U.S. ALUMINUM PLANT LOCATIONS



PLANT AND POPULATION CENTER RELATIVE LOCATIONS
ALL U.S. PRIMARY ALUMINUM PLANTS



NON-HSS PROCESS
U.S. PRIMARY ALUMINUM PLANTS
(80% OF U.S. PRODUCTION CAPACITY)



production, the industry-wide fume energy above 70°F is estimated in 1985 to reach 8.205×10^9 Btu/hr. Replacement of fossil fuel (energy value 129,500 Btu/gal: burner efficiency 100%) by this energy would result in a savings of 13.2×10^6 barrels of oil per year. If a burner efficiency of 70% is used in the calculation, then the predicted savings increases to 18.9×10^6 barrels of oil per year.

3.0 SELECTION OF PROCESS ENERGY RECOVERY APPLICATION AND THERMAL ENERGY STORAGE SYSTEMS – TASK II

The objectives of Task II were to reevaluate the available primary aluminum plant waste heat sources and, on the basis of the Task I survey and preliminary engineering economic analyses, reevaluate the baseline waste heat recovery/utilization application and alternative recovery/utilization applications. The best process energy recovery/utilization application and its appropriate storage devices would then be selected for detailed engineering and economic analyses during the remainder of the program.

3.1 UTILIZATION OF RECOVERED PROCESS ENERGY

To effectively utilize the energy that is potentially recoverable from the various aluminum reduction plant sources, the following two areas are critical:

1. Establishment of applications that could utilize the recovered process energy
2. Identification of economically attractive energy collection, transmission, and storage systems

As described in Section 2.0, there are several locations within primary aluminum plants that contain high temperature energy and as such, are attractive for waste heat recovery. While these applications are economically attractive, their total conservation impact to the aluminum industry is limited. The most significant conservation impact that can be created by the aluminum industry is to effectively utilize the massive amount of 200 to 700°F energy available from the primary air pollution control systems.

In order to utilize this low temperature energy, several applications external to the plant have been identified. Obviously, where applicable, internal plant utilization of the recovered process energy is preferable, since this reduces the energy input required per unit of product produced, and logistic complications associated with plant shutdown, etc., are not a factor. For applications where external applications are involved, backup systems, etc., must be included.

The following sections discuss both internal and external utilization of recoverable energy from the aluminum reduction process.

3.1.1 Internal Utilization of Recoverable Process Thermal Energy

The energy recovered from the various process areas in aluminum reduction plants could be utilized in the overall process either directly as thermal energy, or indirectly by being converted to electrical energy by means of a thermoelectric power plant and used to provide some of the electrical demands of the plant.

Direct Utilization – Due to the nature of the aluminum reduction process, electrical energy provides all of the energy required for the actual electrolytic reduction of alumina to aluminum. Fossil fuels used in the aluminum reduction process are only consumed for secondary processes (remelt furnaces, holding furnaces, anode baking, etc.), or are used as raw materials for the anodes. The energy of the fossil fuels consumed for thermal processes amounts to only about 6.5% of the total process input energy. Any recovered process thermal energy can be used directly in those processes which can utilize the thermal energy, i.e., the cast house operations or the anode baking furnaces.

Due to the temperatures of the various recoverable energy sources, the only direct applications of recoverable energy would be to utilize the cast house recoverable energy in the anode baking furnace, or utilize the same energy in recuperators in the cast house furnaces to preheat the incoming furnace combustion air and reduce fuel consumption. Even if all of the recoverable energy from cast house were utilized in the baking furnace, some additional outside energy in the form of fossil fuels would still be required to reach the maximum baking furnace temperature of 2,100°F.

Based upon preliminary cost analyses, it appears to be more economical to utilize the recoverable cast house energy within the cast house for furnace recuperation than to transport the energy to the anode baking furnaces.

Indirect Utilization – In an indirect utilization application, the recoverable thermal process energy would be stored and then upon demand, converted into electrical energy by means of thermoelectric generator. This electricity would then be used internally within the plant to reduce the plant's outside electrical consumption. This concept would allow the aluminum reduction plant to reduce its external power demand during times of peak electrical utility loads.

The maximum amount of electrical energy that could be recovered from each of the various process areas of the plant is limited by second law of thermodynamics. Using the Intalco plant as an example and a Rankine cycle conversion of this thermal energy to electrical (100°F heat rejection temperature), the amount of electrical energy potentially available from each of the Intalco process areas is presented in Table 3.

The high temperature waste heat stream from the cast house furnaces would be an attractive site for an optimum application study. Recuperators and charge preheaters should be considered as well as a cogeneration system. As the current study is concerned with application for storage in the low temperature waste energy, and as the high availability waste stream represents less than 20% of the energy available, the current study concentrated upon the low temperature streams.

The operation of Rankine cycle turbogenerators in a "bottoming mode" is known and the economics and efficiencies well established by many investigators. The very low overall efficiency of these systems, compared to the very high utilization achievable through district heating systems, causes the latter to be more attractive.

Table 3
INDIRECT RECOVERABLE PROCESS ENERGY
RANKINE CYCLE CONVERSION
INTALCO ALUMINUM PLANT

Energy Source	q _{available} Btu/hr	Assumed Average Temp. (°F)	Estimated Conversion Efficiency (%)	Total Electrical MW	% of Plant Electrical Requirement
Anode baking furnaces	8.3 x 10 ⁷	372	7	1.7	0.4
Cast house (remelt, holding and homog- enizing furnaces)	7.08 x 10 ⁷	1,200	19	4.0	1.0
Reduction cells (energy available in primary air pollution control system gas stream)	3.3 x 10 ⁸	260	6	5.9	1.4

3.1.2 External Utilization of Recoverable Process Thermal Energy

Application – In recent years, a considerable amount of work has been devoted to the utilization of low-grade thermal energy. This work was performed not only for waste heat utilization, but for utilization of geothermal and other low-grade energy sources. The six basic application areas other than electrical power generation are: greenhousing, open field soil warming, aquiculture, snow and ice control, comfort conditioning, and low temperature industrial process energy.

Greenhousing – Of the three agricultural applications, the heating of greenhouses with low-grade heat has received the most attention. Several pilot operations are currently in operation; for instance, a 5-acre complex in Abu Dabi produces 1 ton of vegetables per day. Waste heat from a steam-electric plant in Romania is pumped 4 miles to a 325-acre greenhouse complex.

Most existing products make use of the heat only during the winter months. A cooling tower is used to dissipate that energy during the summer. A backup heat source (fossil fuel) is provided to avoid crop loss in the event of a power plant shutdown. Thus, capital investment is relatively high due to redundant systems. Note that for the system in question, cooling towers or alternate dissipation systems are not required. The industrial process currently operates satisfactorily, and no change in this ability is foreseen.

Retrofitting existing greenhouse complexes for low-grade heat utilization should be a relatively simple matter as the most common heating system is a hot water or low pressure steam grid, designed for fluid temperatures in the 200 to 230°F range. To convert to low-grade heat in the 200 to 220°F range requires no change in the piping system; only the controls.

A severe disadvantage is found when the waste heat source is considered for greenhouse heating:

1. The high capital expenditure associated with greenhouses requires a crop which shows significant growth improvement in a greenhouse environment and which commands a high price. Known crops which meet these criteria are tomatoes, cucumbers, lettuce, and decorative plants (flowers, house plants). None of these are staple crops. It is difficult to justify expenditure of public funds towards the creation of luxury goods, when population growth trends indicate a staple food shortage in the future.
2. A second disadvantage is that greenhouse facilities are not necessarily found near aluminum plants.

Open Field Soil Warming – The concept of extending the growing season for open field agriculture through soil warming has been under investigation for several years. Frost control for citrus orchards is usually included under this heading. When compared to greenhousing, this concept requires significantly less overall expenditure per acre; hence, crops are not limited to luxury foods and decorative plants. Open field soil warming experiments with potatoes in Minnesota and with several crops (notably bush beans) in Oregon have shown that double cropping is feasible in some environments, with some staple crops. On an annual basis, land productivity was increased 30 to 70% (the second crop generally shows lower yield). In the case of potatoes, the second crop was also of lower quality (smaller), but acceptable on a nutritional basis.

A significant disadvantage for the open field soil warming application is found in the annual demand profile. The costs associated with heating toward a full year growing season are prohibitive; hence, the system actually works to allow earlier spring planting and later fall harvesting. During the winter months, the energy may be dissipated by the field system, but not to a useful purpose. It is unlikely that the power required to pump the heat transfer fluid to the field would be justified under this condition as existing dissipation means operate satisfactorily. During the summer months, dissipating heat in the soil may be harmful to the crop, especially during the day time. Hence, a soil warming system must justify its expenditure based upon operation for only spring and fall operation, perhaps 50% of the year.

An unexpected disadvantage of open field soil warming was noted in the Oregon studies. Considerable difficulty was experienced with disease and pest control in the heated plots when compared to the control plots. Experimenters attributed this phenomenon to large

flocks of birds which were attracted to the warmer soil, as well as the more favorable incubation conditions. Bird damage to the crops was also more severe in the heated plots.

Heating of barns and stalls for increased protein production from domestic animals has been suggested, but no data was found to indicate significant improvement by this means.

Aquaculture – Low-grade waste heat is used to improve aquaculture yields in several countries, notably Japan, Western Europe, and the U.S.A. Many additional long-term projects are suggested against the future worldwide food shortage.

In Western Europe, carp forms a significant enough portion of the protein diet to be considered a near-staple commodity. The carp culture industry is an established one, and pond heating exists on a cost competitive basis. Carp growth rate is sensitive enough to temperature so that fish can be brought to marketable size in three seasons in heated pools, when four seasons are required in unheated pools; thus a 33% yield increase is possible.

In Japan, Red Sea bream, Crimson Sea bream, eels, abalone, yellowtail, spiny lobster, blue crab and prawns all have been evaluated as crops for waste heat augmented aquaculture. Most of the work to date has been research or nonprofit operation. In Japan, as in many other democratic countries, the charter of utility companies does not include the sale of heated water, nor the production of food. This may explain the "nonprofit" nature of installations to date. In the USA, commercial aquaculture is accomplished without heating with catfish (in the Southeast) and trout in the Northeast, Mountain and Northwest regions. Studies have shown these indigenous species benefit very little from heated environments in the regions where a market exists for them. It is likely that a catfish production facility in the Northern latitudes would benefit from heating the ponds; however, no market for the product exists in these regions.

Two heated commercial aquaculture ventures are in operation in New England. Both utilize the cooling water effluent from large power generation stations "by agreement" with the operating utilities. Coho salmon and oyster seed are produced. In the case of the oysters, growing in heated environment to marketable size has proven unprofitable. "Seed" are started in the heated effluent, then transferred to a natural marine environment for most of their growing cycle. Studies showing economic feasibility are reported for a third scheme involving production of fingerling rainbow trout during the winter and fresh-water Asian prawns during the summer. This could also be viable in the Pacific Northwest climate, although no indication was found that it is under consideration. Clams, scallops, spiny lobsters, and oyster seed are under study in California as products from waste heat augmented aquaculture.

Many forms of algae are suggested as a future source of high protein animal feed, or human protein supplement. Algae shows significant growth enhancement in heated water (most cooling towers and ponds incorporate algicides to avoid clogging and fouling). Currently,

harvesting and processing techniques are under study. Processing is especially critical as the product must be dried and heated to make the protein digestible. The required temperature is in excess of 100°C, and much water must be evaporated; hence, at the current time, the processing requires so much energy that the output product is not competitive with other protein sources (soy beans, etc.).

Comparing the requirements of heated aquaculture systems with the characteristics of the aluminum industry waste heat source, the following conclusions are drawn:

1. The requirement for storage is eased as the pond forms its own storage reservoir.
2. The annual variations in available and required energy can be accepted by incorporating different species in winter and summer months.
3. Of the three agricultural applications, aquaculture will require the least expenditure for user-end heat exchangers. The air side of the greenhouse heat exchanger is the limiting factor there, while the very diffuse geometry required for soil warming results in high expense.
4. As heated aquaculture is not currently a widespread industry in the U.S., application of the waste energy to this use presupposes the development of a new industry. While not specifically forbidden, it would be preferable to choose an application where the waste heat could be used to replace a demand for some higher grade energy form.

Snow and Ice Control – Geothermal energy is used to keep certain very critical roads clear of snow and ice. The waste heat from a nuclear plant is proposed as a method to keep the St. Lawrence Seaway clear of ice. While no significant applications of this type are known for the Seattle area, it is possible that this could form a viable use in other parts of the country. Basically, energy is required only a few months per year. However, very low grade (30°C) energy could be used. Energy savings takes the form of reduced gasoline consumption of municipal snow plows and sand and salt trucks, a difficult parameter to quantify. Overall benefit must include the reduced accident probability, which is even more difficult to reduce to a dollars basis.

Space Heating – Space heating for human comfort accounts for a very large fraction of the national expenditure of fossil fuel. In recent years, a growing fraction of the comfort heating is accomplished electrically. All else being equal, the replacement of electric heating energy with waste energy presents the greatest net savings, both on a national and a local level.

Theoretically, there is no reason why energy at any temperature greater than room temperature (70°C) cannot be used to heat space. Practically, temperature differences are required to encourage energy transfer; and the higher the source temperature, the lower will be the costs associated with equipment purchase.

Both residential and commercial buildings may be considered as potential applications. Experience with geothermal space heating systems shows greater economic justification for systems where the energy density is high, i.e., high rise residential and larger commercial buildings.

Space heating is an existing demand for any site under consideration. Individual variations in specific sites are a matter of distance from the source to the demand area and the demand density.

Space heating has the potential for fossil fuel substitution either directly (through the replacement of existing oil or gas furnaces) or indirectly (through unloading fossil fired, electric generating plants for replacement of electric heating systems).

District space and water heating systems have been widely used in Europe and elsewhere for many years in both residential and commercial heating applications. The energy sources for these systems have included dedicated boilers, cogeneration with thermal electric plants, and in some limited instances, waste heat recovered from nearby industrial process plants. In the United States, due to the low cost of energy, district heating systems have been primarily used for only large commercial applications.

The temperatures involved in the various district heating system vary widely from system to system, depending upon somewhat arbitrarily chosen system operating constraints. In Denmark, for example, by law, the maximum temperatures allowed in internal installation are 194°F. The district heating temperatures compare very favorably to the 185 to 300°F temperature, at which bulk of the recoverable energy in primary aluminum plants is available.

Low Temperature Process Heat Substitution – A significant amount of fossil fuel is expended in heating low temperature (230 to 300°F) processes. The food processing industry is a good example. Generally, product quality is highly dependent upon accurate temperature control. Neither lower nor higher temperatures can be tolerated. The concept of increasing the temperature of low-grade heat via a heat pump to the desired process temperature has been suggested for many low-grade heat sources.

Whereas there may be specific situations where an aluminum waste heat recovery system could supply low temperature process heat demands to nearby industrial site, selection of this use as the *baseline* would be unnecessarily restrictive.

3.1.3 Recovery Application Selection

Of the various waste heat recovery applications examined, the baseline district heating concept shows the greatest fossil fuel replacement potential. The waste heat available and hence the potential for energy savings for the waste heat recovery application is estimated to be over 80% of the total recoverable waste heat from the primary aluminum plant sources.

Based upon the Task I waste heat survey and the above analysis, the baseline (district heating system) waste heat recovery/application concept was determined to be the best waste heat recovery/application and was used as a basis for the remaining analysis efforts.

It should be noted that the goal of use selection is to choose the most representative use to which the low-grade energy would be applied if made readily available on a national basis, so that the benefits of making the energy available can be correctly established. Nothing herein said should be construed to forbid a nearby greenhouse system or industrial process from subscribing to the heating system. In fact, such situations would improve the overall economic performance of that individual system. Provision for the residential and commercial space heating demands has been chosen as the most likely end use and as the end use with the highest fossil fuel replacement potential.

3.2 STORAGE SYSTEM SELECTION

3.2.1 District Heating Storage Requirements

Energy storage plays an important role in efficient utilization of the recovered process energy for district heating applications. As aluminum production is essentially a continuous process, the energy which could be recovered from the process and utilized is produced at a constant rate 24 hours per day, 365 days per year. The energy requirements, however, of district heating systems vary widely on both a daily and seasonal basis. An energy recovery system sized to handle the daily peak demand without energy storage would be under-utilized during all but the peaking portion of the demand cycle and would be unable to utilize the excess energy. Incorporation of energy storage in the district heating system reduces the peak energy demand from the source and allows the same energy supply to meet the energy demands of a greater number of users.

The same type of load leveling problems that occur on a daily basis also occur on a seasonal basis. District heating requirements are higher during the winter months than during the summer. Depending upon the location, the average energy demand for the year (yearly load factor) is less than 35% of the peak load.

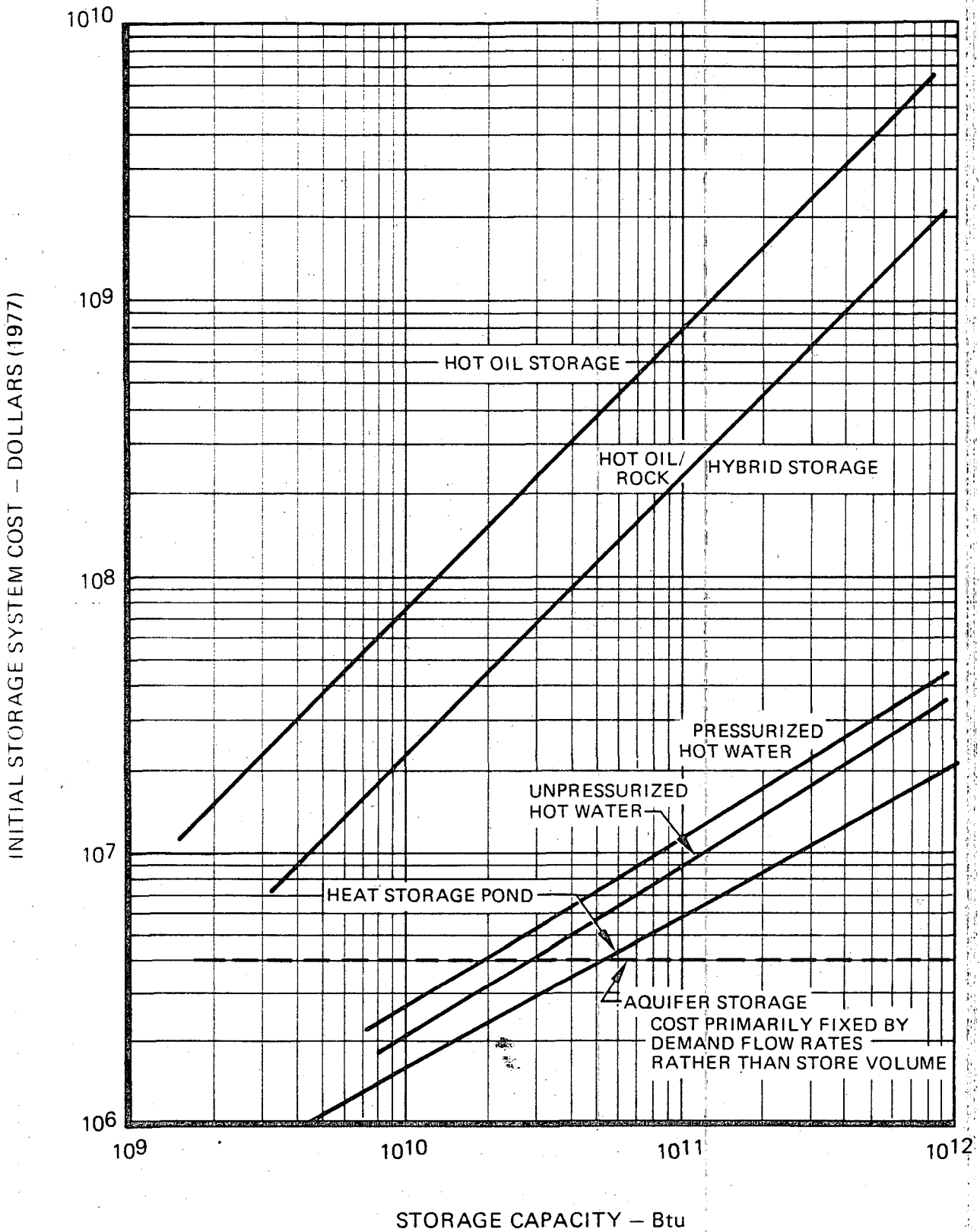
3.2.2 Storage System Concepts

Six basic types of thermal energy storage systems were examined in detail for use with the district heating system. These storage concepts were: 1) unpressurized hot water in steel tanks (storage temperature less than 212°F); 2) unpressurized hot water insulated heat storage ponds (less than 212°F); 3) moderately pressurized hot water tankage (212 to 250°F); 4) aquifer storage (less than 250°F); 5) unpressurized hot oil tankage; and 6) hot oil/rock hybrids (less than 275°F). Latent heat of fusion and rock bed thermal storage systems were ruled out initially due to their high cost.

Each of the various storage systems was evaluated on the basis of the following criteria:

- a. Initial storage system capital cost – \$/Btu of storage (based upon estimates shown in Figure 11)

INITIAL STORAGE SYSTEM CAPITAL COST



- b. Recurring maintenance cost – \$/Btu/year (based upon initial cost and industrial experience where applicable)
- c. State of the art (subjective evaluation of degree to which storage system technology will be developed by the estimated wide-scale implementation date (1985) for district heating system)
- d. Safety, reliability, and potential environmental hazards (subjective evaluation)
- e. Peak storage temperature capability
- f. Site applicability – extent to which storage system is site specific, i.e., can only be used at some sites and not others
- g. Energy utilization (evaluation of the effect of storage system on the ability of system to maximize the energy recovery from the aluminum plant, i.e., seasonal storage capability)
- h. Storage efficiency (evaluation of the extent to which energy placed in the store can be recovered from the store).

The results of this evaluation effort are summarized in Table 4. The site applicability of aquifers was based upon a very preliminary study of known aquifers located in proximity to the various aluminum plants. The storage efficiency of aquifer storage systems was based upon efficiency estimates in the literature. The storage efficiencies of the other concepts were based upon detailed heat transfer analysis.

Comparing the three best storage systems (unpressurized hot water in steel tanks, aquifer storage, and heat storage ponds, respectively), the potentially lowest cost storage system is aquifer storage. The limited number of proven applicable sites and the fact that aquifer storage technology has not been reduced to engineering practice, resulted in a decision to base the remainder of this study upon the available technology of unpressurized steel tanks, recognizing that more favorable (economically) systems may result when aquifer technology becomes proven.

Table 4
STORAGE SYSTEM EVALUATION

Criteria	Weight	Hot H ₂ O (Steel Tank)	Pressurized H ₂ O	Aquifer Storage	Hot Oil	Hot Oil Hybrid	Hot H ₂ O Insulated Heat Storage Pond
Initial cost/Btu	3.0	7	4	10	1	2	8
Maintenance cost/Btu	2.0	8	7	7	9	7	7
State of the art	1.0	9	8	1	9	8	2
Safety	1.5	8	5	10	8	8	6
Reliability	2.0	9	9	7	9	9	9
Peak temperature capability	0.8	6	8	10	10	10	6
Environmental hazards	1.0	9	8	9	2	4	7
Storage density	0.5	5	6	3	3	4	5
Site applicability	2.0	10	10	5	10	10	10
Energy utilization	3.0	5	5	9	5	5	7
Storage efficiency	3.0	9	9	7	9	9	8
Total weighted score		154	133.7	148.5	133.5	134	146.3

V03179

35

GEO-HEAT CENTER

4.0 PLANT OPERATIONAL DATA COLLECTION – TASK III

Based upon the survey results, the Intalco Aluminum plant is representative of large, modern aluminum plants. The goal of the Task III efforts was to gather information on plant operation and waste heat release as would be applicable to the district heating waste recovery application.

4.1 ELECTROLYTIC REDUCTION CELLS/PRIMARY AIR POLLUTION CONTROL SYSTEM WASTE HEAT SOURCE

The Intalco plant has 720 prebake electrolytic reduction cells formed into three potlines, each containing 240 cells in series. Each potline (A, B, or C) is housed in two buildings (six total) as shown in Figure 12. The buildings are erected side by side; and each measures 1,450 feet long, 125 feet wide, and 50 feet high. The prebake reduction cells, each 15 feet wide, 25 feet long, and 4 feet deep, are buried in trenches in the floor of the buildings. The CO, CO₂ pot gases and dust particles evolved during the reduction process are collected into the primary air pollution control system by means of metal hoods built over each of the pots. Figure 13 shows a number of reduction pots and hoods. Air from inside the buildings is withdrawn from the top of the pots through the metal hoods to prevent the pots from overheating. The exhaust gases are transported through large diameter ducts to one of six dry scrubbers (baghouses) where the dust and fluorides are removed and the gases vented to the atmosphere. A typical baghouse and ducting are shown in Figures 14 and 15.

4.1.1 Primary Air Pollution Control Gas Temperature and Flow Rate

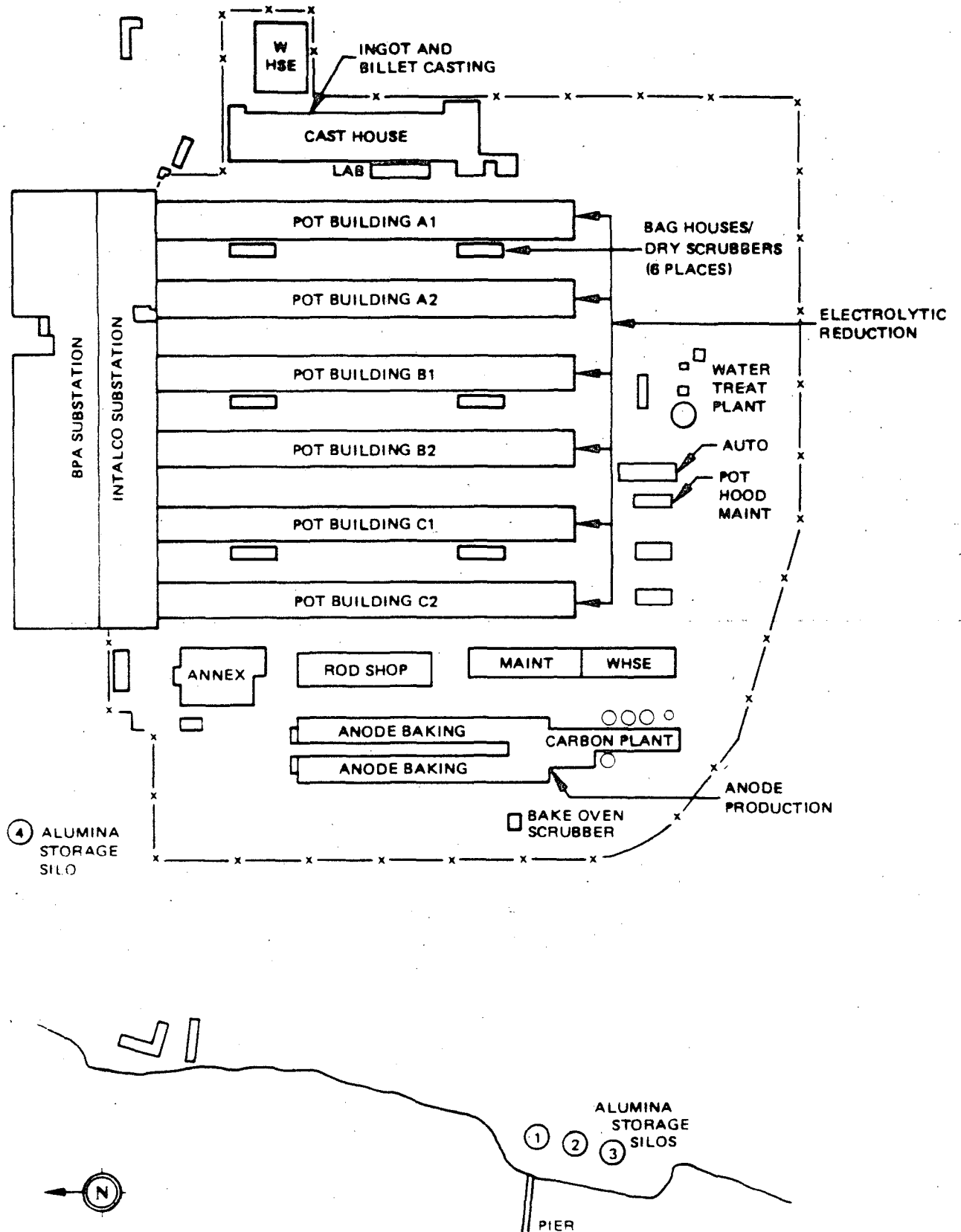
After consultation with the Intalco technical staff, a group of 10 "typical" cells was selected. These 10 cells were then instrumented with thermocouples to monitor the duct gas temperatures, the potroom temperature, and the outside air temperature.

Due to the high electrical hazard associated with the cells (each cell operates at over 100,000 amps), special care had to be taken to electrically isolate the thermocouples and protect operating personnel. These precautions included special insulated boots for the test personnel, use of isolation transformers, and electrically insulated equipment containers.

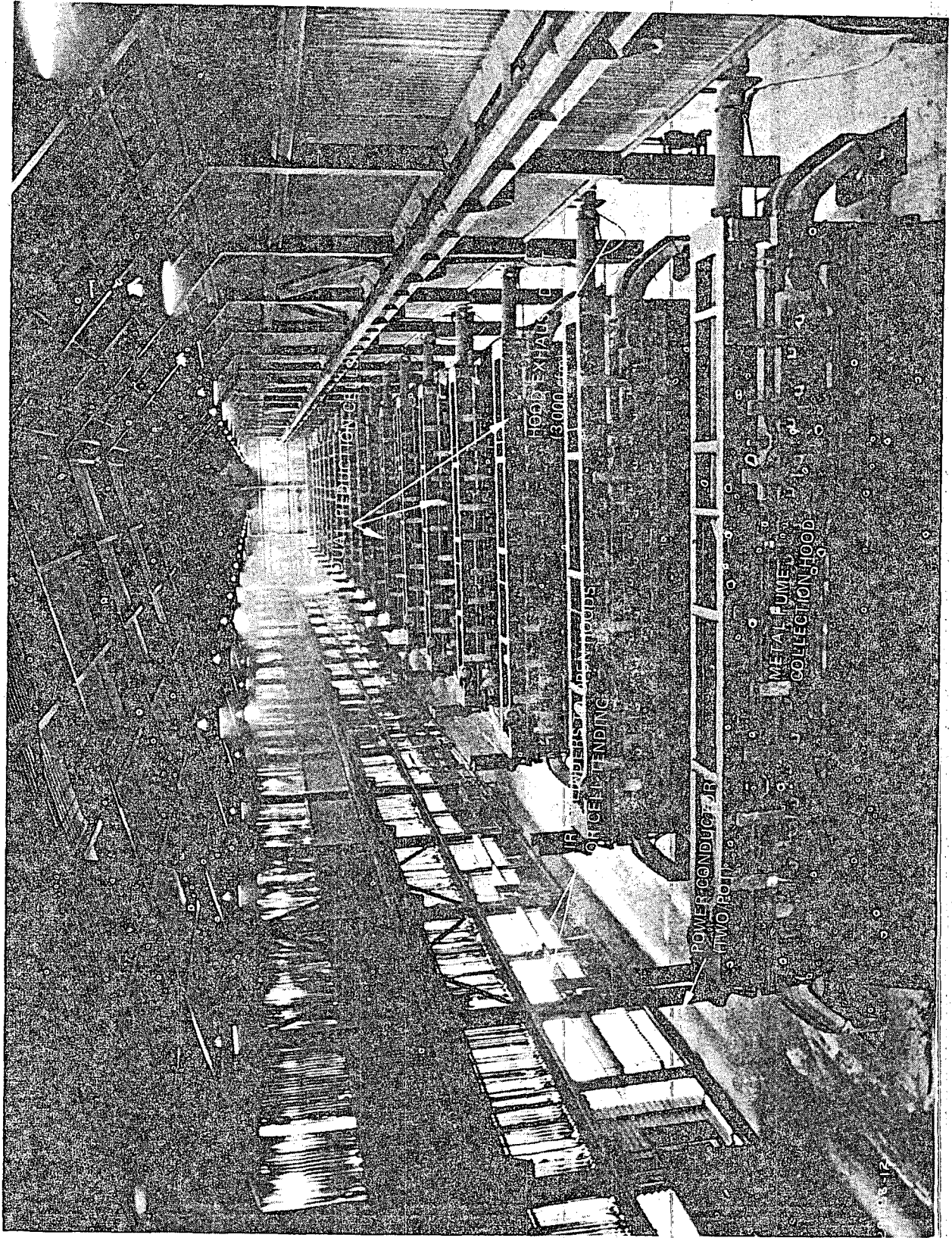
The thermocouple temperatures were recorded over a period of 1 month. The temperature data, in conjunction with Intalco-supplied monthly and annual data, are summarized below.

The average gas flow rate from each cell into the primary air pollution control system is 3,000 acfm, or approximately 6.87×10^6 lbs/hour for all 720 cells. The flow rate is checked by Intalco on a monthly basis and adjusted as required.

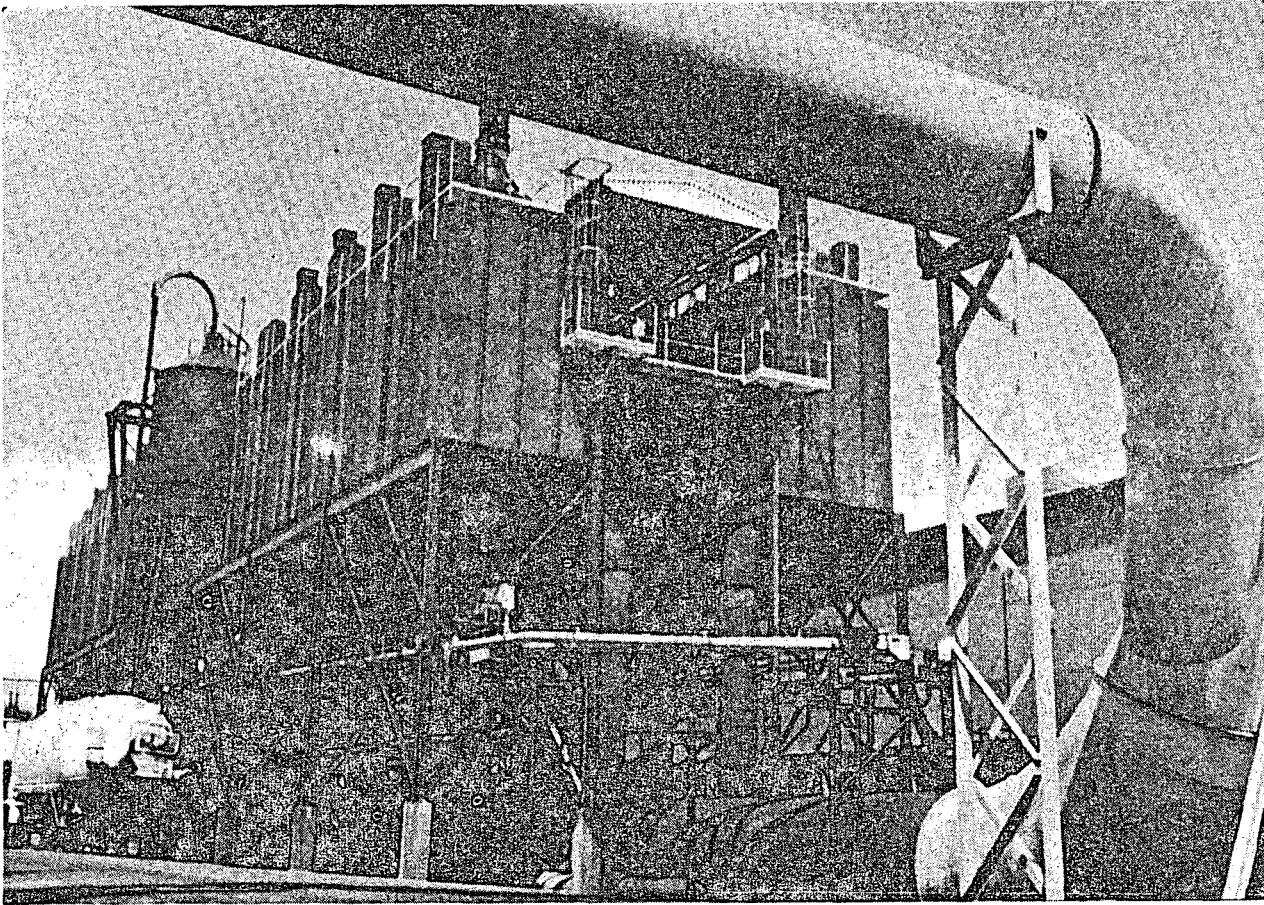
INTALCO PLANT LAYOUT



1/14 OF ONE INTALCO POTLINE



TYPICAL INTALCO BAG HOUSE



29008-20

40

Figure 14

AIR POLLUTION EQUIPMENT ON POTLINES

29008-10

41

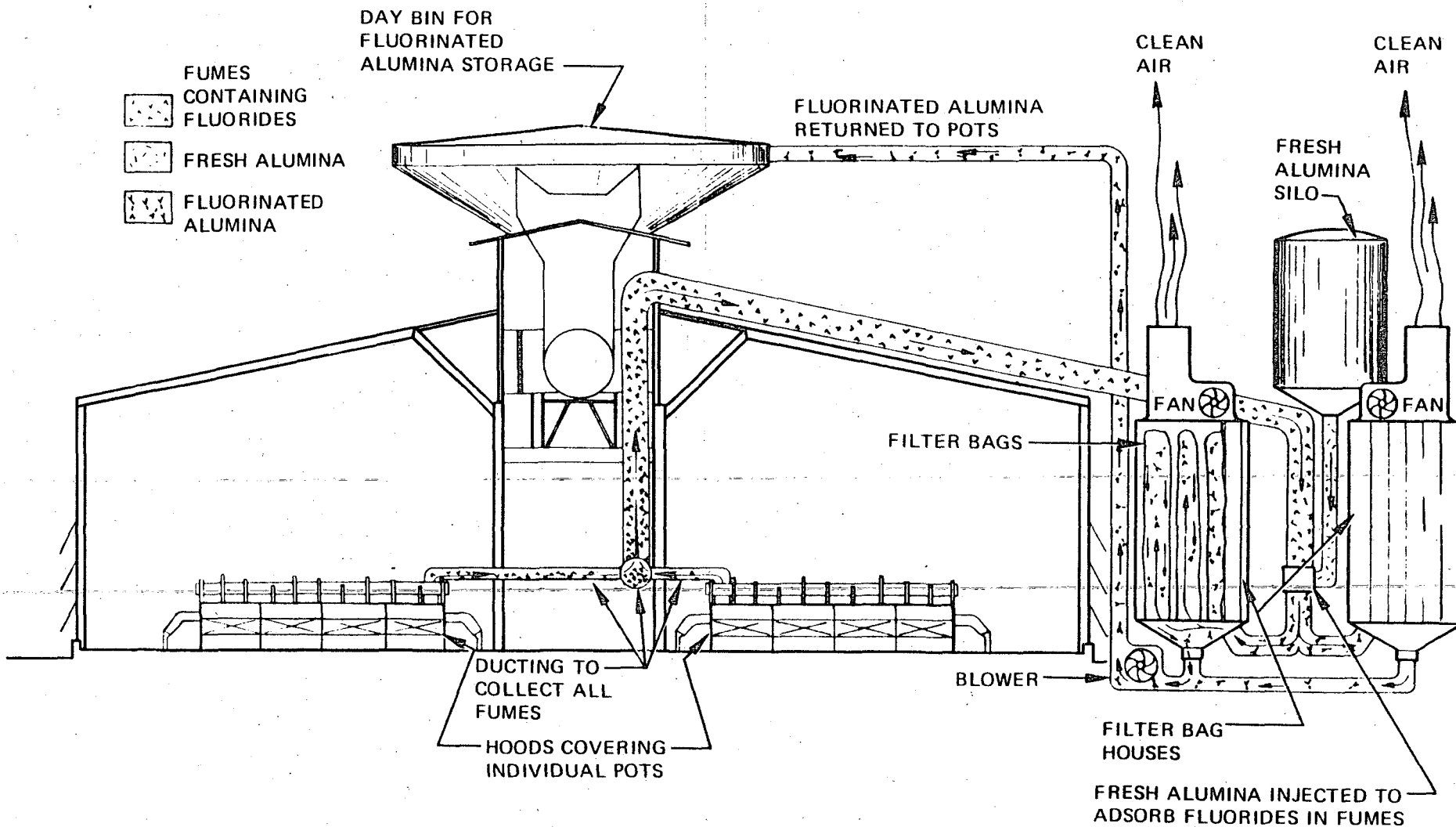


Figure 15

Each cell hood is opened a number of times during each working day for normal maintenance. Each cell hood is open an average of 5 to 7% of the time. When the hood is open, the temperature in the duct coming off the cell drops by approximately 100°F. Since only 5 to 7% of the cell hoods are open at any given time, the resulting influx of cooler air produces only a 5°F reduction in the average gas temperature in the pot fume collection ducts. Each time any given cell hood is opened and closed, there may be a slight change ($\pm 20^\circ\text{F}$) in the ensuing steady-state pot duct temperature. This is believed to be primarily due to random variation in the effectiveness of the hood edge seals. This effect averages out by the time 60 cells are manifolded into the larger ducts.

The average temperature in the Intalco fume collection ducts is effected by the outside ambient air temperature (ambient air is used to cool the cells) and the nominal aluminum production rate. The effect of the outside ambient air temperature on the average fume collection duct temperature is shown in Figure 16. The data presented in Figure 16 is for two particular blocks of 60 cells (identified as 4N and 4S) which are representative of Intalco as a whole.

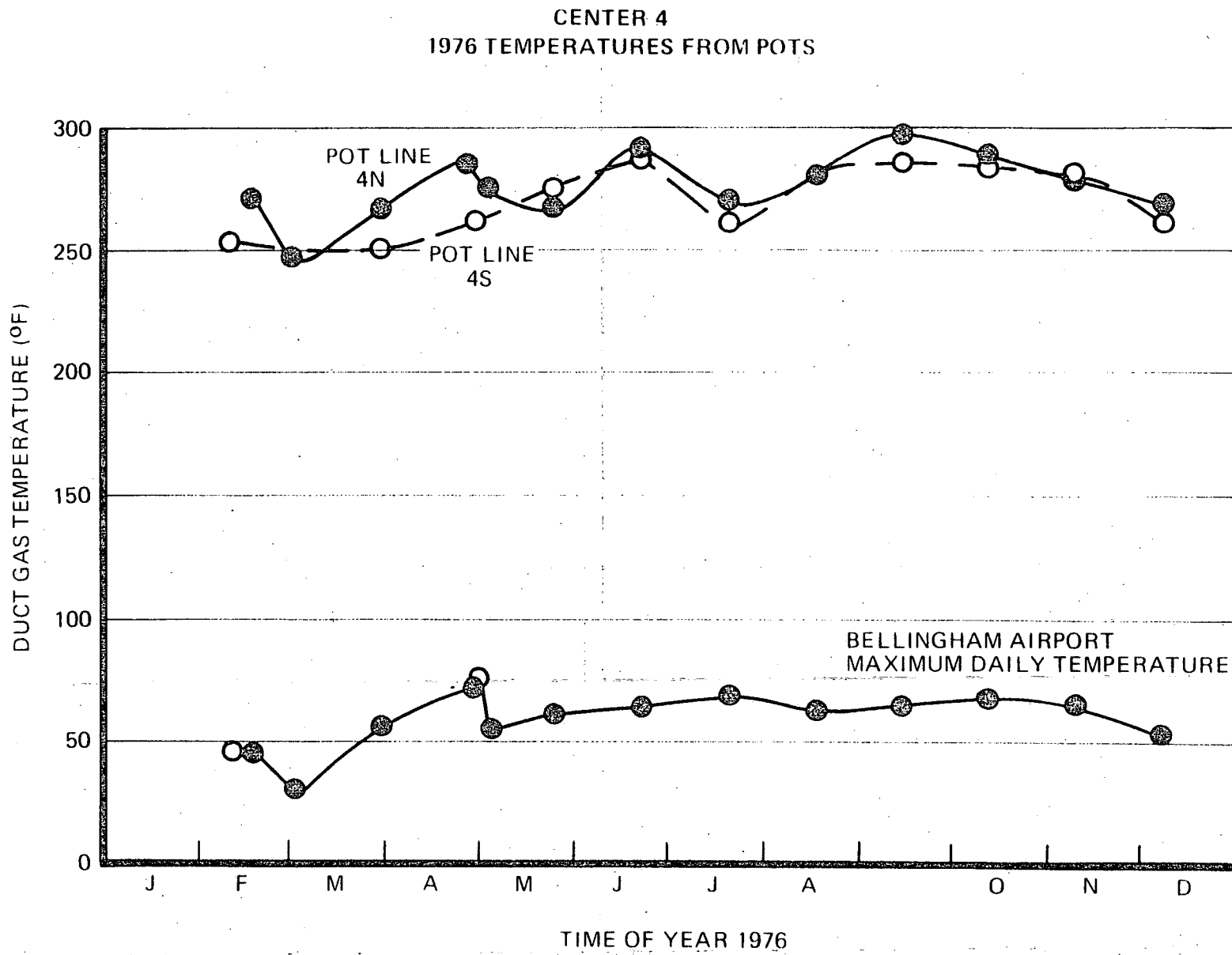
Based upon discussions with plant personnel, a minimum average duct gas temperature of 260°F can be achieved without undesirable effect upon plant operations.

During periods of low power availability, the production rate is reduced to conserve power. The lower production rate may reduce the average duct temperature by as much as 20°F, depending upon the extent of the production cut-back.

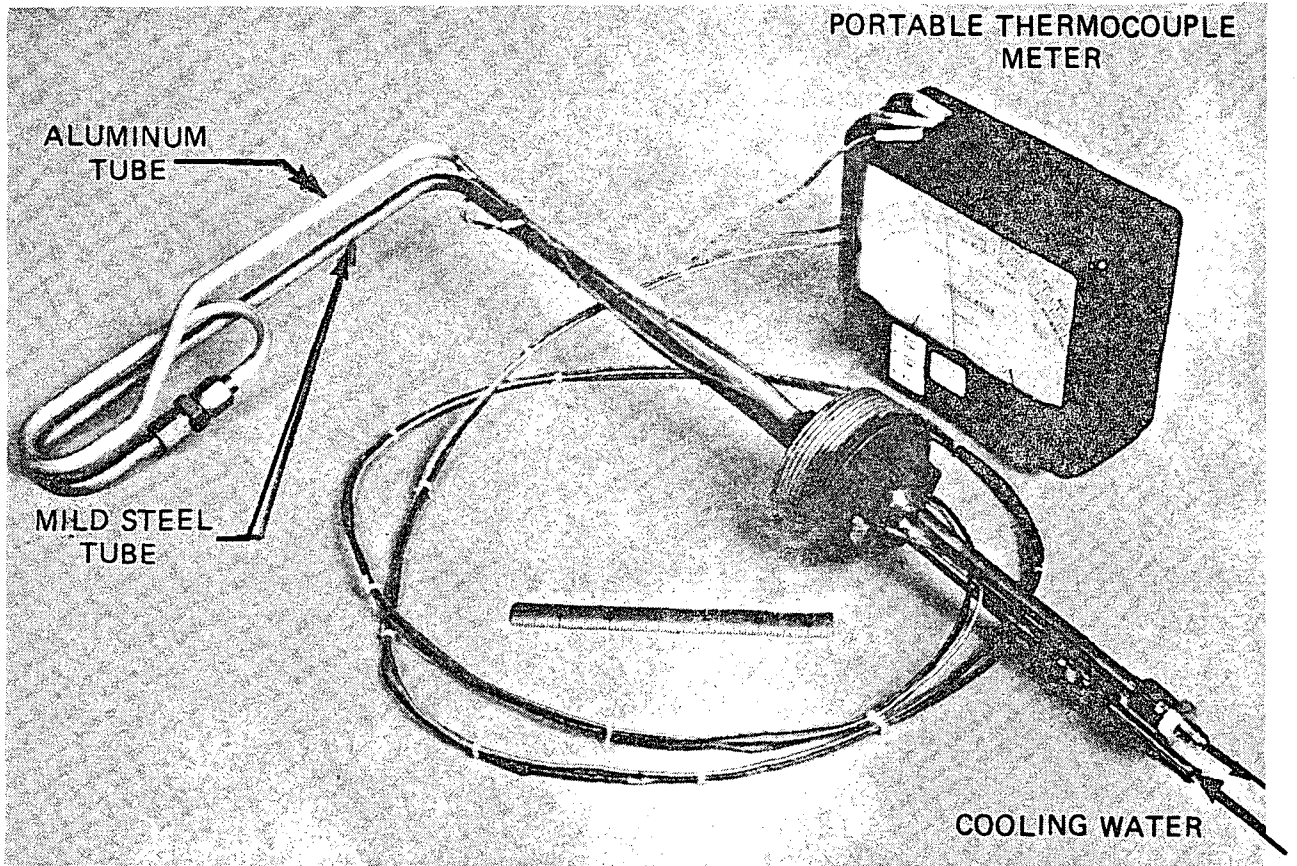
In addition to the thermocouple measurements, additional temperature measurements were made of the 10 "typical" cells, using an infrared pyrometer. These measurements suggest that by insulating the hoods, that over 25% more energy could be recovered. Recovering this energy might require, however, changing the cell duct gas flow rate to maintain the proper cell heat balance. As the increased gas flow rate might require expensive changes to the plant's primary air pollution control system in the form of larger fans and bigger ductwork, the existing duct gas flow rates and temperature were used for the Tasks V and VI energy availability analyses.

4.1.2 Test Heat Exchanger

To evaluate potential heat exchanger corrosion and surface contamination effects, the instrumented heat exchanger, shown in Figure 17, was installed in one of the larger ducts in the primary air pollution control system near the location envisioned for full-scale heat exchangers. The device incorporated both steel and aluminum tubes, arranged so that each material was exposed to stagnation flow, cross-flow, and counter-flow in the fume duct. The heat exchanger was removed from duct at intervals and examined for corrosive attack and surface fouling.



HEAT EXCHANGER



The heat exchanger was tested with surface temperatures ranging from 80 to 205°F. These are believed to be representative of the range of heat exchanger surface temperatures that would be expected in a full-scale heat exchanger. Over the 4-month period that the heat exchanger remained in the duct, no significant corrosion or erosion of either the aluminum or steel was found; and the performance of the heat exchanger was consistent throughout the test.

5.0 ESTABLISHMENT OF INTERFACE DEFINITION – TASK IV

The interface requirements for the primary aluminum plant waste heat/district heating system can be divided into three distinct areas: governmental restrictions and requirements, plant/system interface requirements, and user/system interface requirements. These interface requirements will vary to a limited extent, depending upon the plant type, configuration, and its location. The interface requirements for the Intalco/Bellingham district heating system described in the following paragraphs are believed to be typical of the nation as a whole.

5.1 GOVERNMENTAL RESTRICTIONS AND REQUIREMENTS

The governmental restrictions and requirements described below are based upon discussions with the Washington State Public Utilities Commission, the Bellingham Engineering Department, and the Whatcom County Planning Commission.

5.1.1 Establishment of District Heating Utility in Bellingham

There are two possible forms that a district heating utility might take; either a privately owned utility, or a public utility wholly owned by the City of Bellingham.

If a privately owned district heating utility were to be established, the private utility would have to get a franchise from both the City of Bellingham and Whatcom County (both Bellingham and Intalco are located in Whatcom County, and any pipeline connecting the two would have to cross a minimum of 10 miles of land under County authority). These franchises would be granted by the Bellingham City Council and the County Government, respectively, after separate hearings on the desirability (from the standpoint of the local citizens) of granting the franchises.

Once granted a franchise, the utility would then be liable for an 8% utility tax on its gross sales. The proceeds from the tax would be split between the County and City in proportion to the sales in their respective areas.

If a city-owned utility approach were selected and approved by the Bellingham City Council, the City would sell revenue bonds to finance the utility.

The Washington State Public Utilities Commission does not regulate district heating utilities. It does, however, regulate municipally owned utilities furnishing other services. It is possible, however, that if large-scale implementation of the district heating concept occurs, the State Government could extend the utility regulations to include district heating systems.

5.1.2 Easements for Pipeline Right-of-Way and Installation of Pipe

The hot water transmission line would run from 10 to 14 miles through Whatcom County from the Intalco plant to Bellingham, depending upon the transmission pipeline route selected. Where the transmission pipeline was installed within the confines of the county road easements, a construction permit would be granted after county approval of the district heating franchise. A condition of the construction permit would include repairing any damage done to highways, etc., during construction. If the pipeline were to be run cross country rather than within road easements, right-of-way would have to be negotiated with the individual property owners involved.

Within Bellingham, the distribution system would be installed within the road easement. For a franchised utility, construction approval for work within the road easement would be granted after a permit application was made to the City. The district heating utility would be responsible for coordinating with the other utilities to determine the location of existing pipes and underground wires prior to construction. After installation of the pipelines, the trench would be refilled and repaved to meet City standards.

Easements across private property to connect to individual users would be arranged at the time service to the user was contracted.

5.2 PLANT/SYSTEM INTERFACE

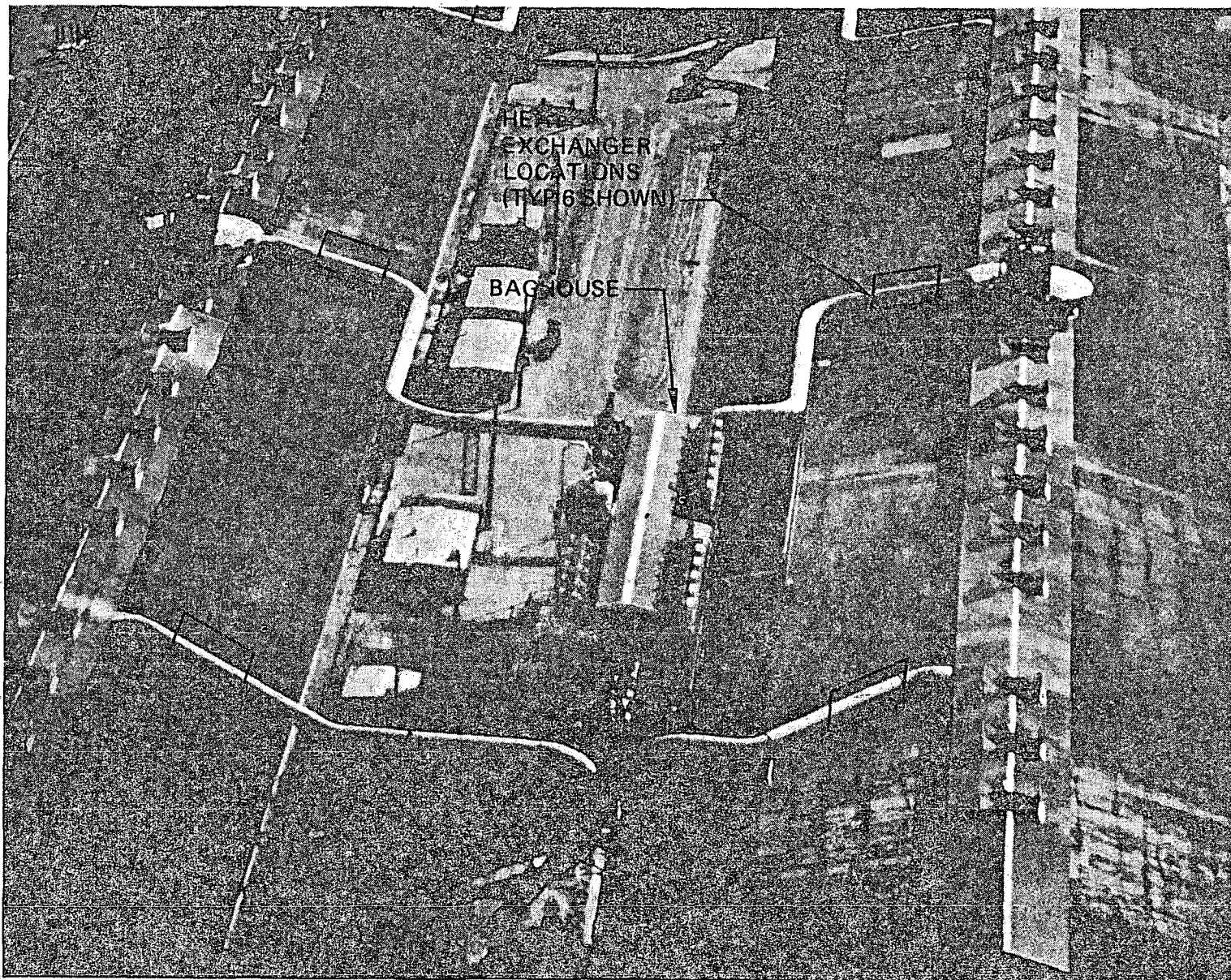
During the course of the program, several discussions were held with the Intalco technical and management personnel concerning potential interface and operational problems between the Intalco Aluminum Corporation plant and the district heating system. The primary requirements from the plant standpoint are that the installation and operation of the plant heat exchangers and associated piping not significantly interfere with plant operations or create a potential hazard for plant personnel.

The major interface between the plant and the district heating system is between the plant heat exchangers and the primary air pollution control system. The major areas of concern with the heat exchanger installed in ducts are:

1. Location of the heat exchangers
2. Pressure drop through heat exchanger
3. Installation logistics

After reviewing the plant and potline building drawings, the best location for the heat exchangers appears to be on the potline building roofs. An aerial view of a baghouse showing the outside fume collection ducts and the proposed heat exchanger locations is shown in Figure 18. Four heat exchangers would be used per baghouse for a total of 24 heat exchangers for the plant. In this location, the heat exchangers are out of the normal working areas of the plant, but are still accessible via the potline building gallery and roof for maintenance, if required.

AERIAL VIEW OF INTALCO BAGHOUSE AND OUTSIDE FUME COLLECTION DUCTS



29014-07

49

Figure 18

Since the existing plant primary air pollution control system fans were sized for the existing pressure drops through the ductwork and baghouse, only a minimal increase in the total pressure drop due to the installation of the heat exchanger can be tolerated. To handle the increased pressure drop larger fans and/or fan motors will be required. The exact increase in fan power requirements will vary, depending upon the heat exchanger size requirements as determined in Tasks V and VI.

Installing the heat exchangers will require opening the ductwork and shutting down the primary air pollution control system in that section of the plant. The cooling air that is normally drawn across the cells of the air pollution control system will be interrupted when the corresponding ducts are opened. In order to maintain the proper cell heat balance, the hoods on the cells must be opened to allow cooling ambient air to reach the cells. The open hoods will allow the fluorides and particulate matter evolved by the cell to escape from the plant. It is estimated that a period of 24 hours, with cells open and the primary air pollution control system shut down, is maximum before any air pollution levels will be exceeded. The installation of each heat exchanger must therefore be accomplished in less than 24 hours.

Molten aluminum handling operations will require continuous use of the major service roads during the installation of the heat exchangers and associated lines. Lines having to cross these roads may either be excavated in sections, tunneled under, or designed to pass overhead above the traffic.

5.3 USER/SYSTEM INTERFACE

The specific interface requirements between the district heating system and the user will vary greatly, depending upon the type of user served and what type of heating equipment is currently installed (assuming retrofitting existing buildings). Any interface installation will have to meet local building and plumbing codes including design, materials, and operating temperatures. A detailed study of specific user equipment in the Bellingham area is beyond the scope of this study, and is proposed for future work. Some general observations, however, may be made at this time.

For a typical installation, the user interface will consist of three separate devices. One device would utilize the district heating system supplied energy to provide space heating to the user. The second would take energy from the district heating system to provide hot potable water. The third is the meter by which the user energy charges are recorded.

The space heating systems currently used in the Bellingham area can be classified into four basic types:

1. Steam supplied
2. Direct electrical
3. Circulated hot water (hydronic)
4. Forced air

The spacing heating systems currently using steam (these would primarily be the larger office and apartment buildings) could be converted over to the hot water district heating system by replacing the existing steam radiators with hot water convectors. While some additional control valves and pumps might be required, the existing steam lines and ductwork would not have to be changed.

The space heating applications which would be converted over to the district heating at minimum cost are buildings which currently use circulating hot water as the heat transfer medium within the building. For these buildings, the only modification required would be those associated with connecting up to the district heating system lines, and bypassing the existing heating boilers. Based upon an estimate by the Bellingham Building Department, approximately 25% of the Bellingham commercial buildings are currently using this type of system.

The majority of the residential users as well as some of the commercial buildings have forced air heating systems, i.e., heated air circulated through ductwork into the various parts of the building. The primary modifications required for these heating systems consists of installing an appropriately sized heat transfer coil in the existing ductwork.

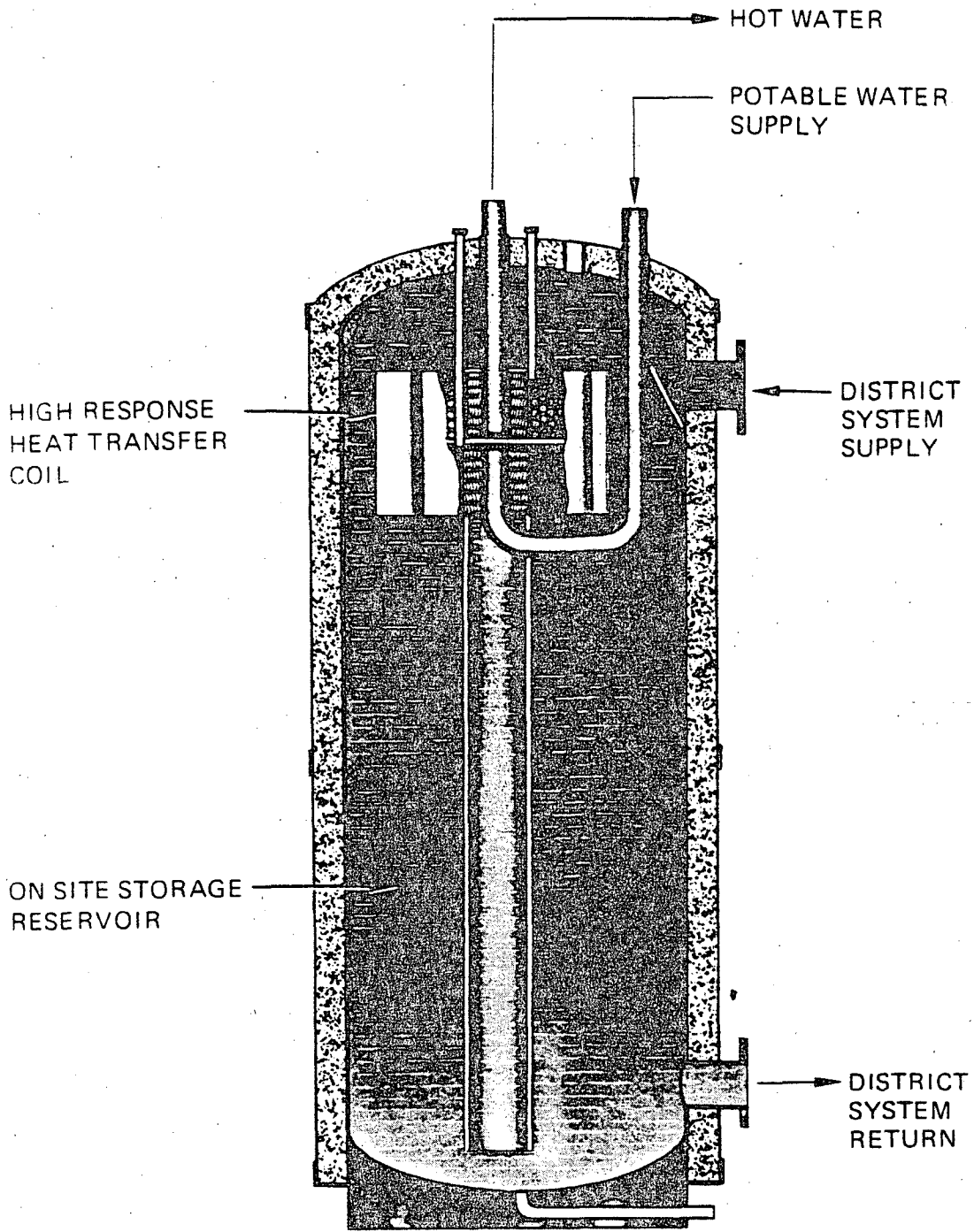
Direct, electrically heated (nonforced air) buildings would require significant building and heating system modifications, including the installation of heat exchangers (room convectors), fluid lines and control valves.

Potable hot water heating would be provided by the district heating system for both commercial and residential customers by means of liquid-to-liquid heat exchangers. In the simplest form, these heat exchangers would consist of a set of heat exchange coils inside an insulated tank, and would replace the users' existing electric or fossil fuel fired hot water tanks. This type of hot water heater, shown schematically in Figure 19, is commercially available in a wide variety of sizes. The on-site storage capacity of this type of unit was not included in the computer analysis; hence, results are somewhat conservative.

The metering system cost is based upon existing water flow meters. As the control system is designed for a 75°F temperature drop over each user system, complicated combined temperature-flow meters are not required.

For any use, the cost of the users' interface devices will be a strong function of district heating systems distribution temperature (temperature to user from district heating system), and the temperature drop of the district heating systems heat transfer fluid (hot water) as it flows through the users' interface device. This last parameter is called the user ΔT . If the user is paying for the interface devices, higher distribution temperatures and lower user ΔT 's are desirable, since they tend to minimize the cost of the user interface devices. From the district heating utilities standpoint, however, the higher distribution temperature increases the cost of the aluminum plant heat recovery heat exchangers and reduces the amount of

DOMESTIC HOT WATER HEATER
TO RECEIVE ENERGY FROM DISTRICT HEATING SYSTEM



recoverable energy available from the plant, and the lower user ΔT 's require a higher flow rate from the district heating utility with larger and correspondingly more expensive pipes to supply the same amount of energy. The optimum distribution temperature and user ΔT are those which would result in minimizing the actual cost of energy delivered to user, i.e., those which would minimize the total capital costs of the systems, including both the cost of the user retrofit and the user interface devices, and maximize the recovered energy.

The costs of the user retrofit and interface devices can be handled either of two basic ways. These costs could be incurred by the user, or the utility could incur the costs. This latter approach would tend to encourage potential users to connect to the systems, since they could connect up to a lower cost energy source (lower than their current fossil fuel source) without having to pay a large connection/retrofit initial cost. The utility could then spread the retrofit costs out and pay them off using receipts from district heating system in much the same fashion that many utilities currently rent hot water tanks and furnaces to their customers.

User retrofit and hookup charges are calculated directly from the energy demand density, which in turn may be related to the equivalent number of residential users. The figure works out to \$687 per equivalent residential user. In practice, a user mix of residential, small commercial and large commercial users will be served as discussed in paragraph 7.1.1.

6.0 SIZING AND PERFORMANCE ANALYSIS – TASK V

The goal of the Task V analyses is to establish the optimum tradeoff between the overall district heating system performance and the size, operation and cost of the various system components. While the majority of the Task V analyses are site specific to a Bellingham/Intalco district heating system, the basic system layout design and operation, and Task VI economic analyses (user energy costs, ROI, etc.) are believed to be representative of the majority of aluminum plants and their corresponding cities.

6.1 ALUMINUM PLANT WASTE HEAT RECOVERY/DISTRICT HEATING SYSTEM – DESCRIPTION AND OPERATION

6.1.1 Description

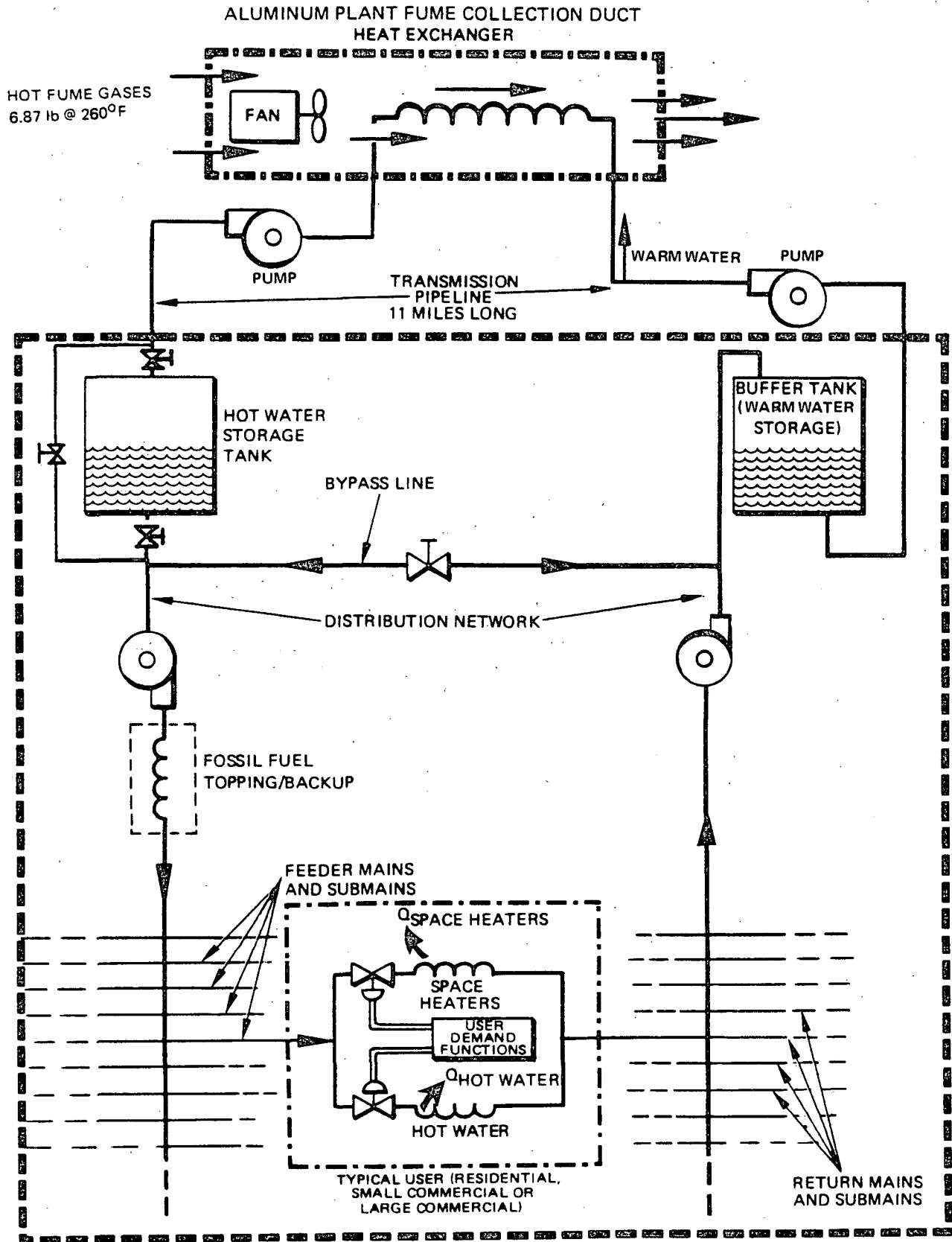
A schematic of the baseline district heating system is shown in Figure 20. The waste heat source is the hot gases in the primary air pollution control (fume collection) system ducts. The total mass flow rate of gas in the Intalco fume collection ducts is 6.874×10^6 lbs/hour at 260°F (this represents an energy source equivalent to 3.13×10^8 Btu/hour above an ambient of 70°F). Energy is recovered from the hot gases by means of counterflow air-to-water heat exchangers installed in the ducts. Based upon the results of the Task IV plant/system interface studies, the waste heat recovery heat exchanger function would be most easily accommodated in the large fume collection ducts between the potline buildings and the baghouses. There would be 24 total heat exchangers, one per duct and four per baghouse. Bypasses are installed in the heat exchangers to limit the maximum water temperature leaving the heat exchanger to a predetermined value, nominally just above the boiling point. Thermal losses in the transmission lines will result in water vapor partial pressure in the tanks less than atmosphere.

Additional fan power will be required in the baghouses to overcome the additional fume collection system pressure drop caused by the presence of the heat exchangers in the ducts.

The transmission pipeline consists of two underground, insulated, polymer-lined, concrete pipes, one carrying hot water to the thermal energy storage facility, and the other pipe being a return line. The circulating water flow rate through the transmission pipeline is constant and independent of the demand.

Since aluminum production is essentially a constant process, the available energy recoverable from the fume collection ducts is produced at a constant rate. The energy requirements of the district heating system will vary widely on both a daily and seasonal basis. The thermal energy storage (hot water) tank in the system acts as a buffer to store energy recovered from the plant during periods of low district heating demand, and supply it to the district heating system during periods when the demand on the district heating system is in excess of the amount of energy being recovered from the aluminum plant.

DISTRICT HEATING SYSTEM FLOW SCHEMATIC



The warm water storage tank acts as an accumulator for water drawn from the hot water storage tank, until it can be reheated and returned.

In the event of an extended period of cold weather and, hence, high energy demand requirements, the hot water thermal energy storage tank may be depleted. User energy demands will be satisfied in that case through a fossil fuel burning alternate heat source. This device will be sized to deliver the entire system demand, if necessary, and thus will also act as an emergency backup system in the unlikely event that energy from the aluminum plant was unavailable. Tradeoff studies indicate that 100% backup capability has minimal cost impact upon the overall system. This feature has been included as potential users invariably asked about failure modes in preliminary discussions.

The user space and hot water heaters are described in detail in paragraph 5.3. The user heat exchangers are sized, assuming a predetermined distribution system inlet temperature (a fixed temperature loss is assumed in the distribution system). The bypass line is used to balance the water flow rate through the system.

6.1.2 Operation

The circulating water flow rate in the transmission pipeline and aluminum plant heat exchangers is constant. Variable energy demand by the distribution system is provided by a variable water flow rate at constant temperature drop. Several features and operating modes are explained in the following considerations of system response to increasing demand.

During periods of low energy demand, hot water from the aluminum plant is pumped into the hot water storage tank. If the tank is partially empty, the tank will be filled at a rate equal to the difference between the transmission pipeline flow rate and the water demands of the distribution system. Under these conditions, the flow rate through the bypass line will be equal to zero, and the warm water tank will be emptying at the same rate that the hot water tank is filling. When the hot water storage tank is filled (and the warm water tank emptied), hot water still flows into the hot water tank, but water is removed from the bottom of the tank at the same rate. This circulation of water through the hot water storage tank is done to maintain the store at the highest possible temperature, and make up for any thermal losses to the tank surroundings. Some of the water leaving the tank will flow through the bypass to the return side of the system at a rate equal to the difference between the pipeline circulating flow rate and the water demand flow rate of the distribution network.

Under conditions where the hot tank is full and demand is less than the supply, existing heat dissipation means will prevail. There is no need to remove the heat from the potline gases from an operational standpoint. This effect can be mechanized by closing off some heat exchangers and allowing them to rise to the gas temperature. Heat exchangers will be designed to withstand the resultant water pressure. The optimized design system, resulting from tradeoff studies, does not enter this mode of operation.

Continuing increase in demand will be met through decreased bypass flow. When demand flow exceeds the transmission pipeline flow, flow in the bypass line reverses. Thus, cooler water is brought from the return side of the system, mixed with inlet side water and delivered to the inlet of the user device at a slightly reduced temperature (the design minimum inlet temperature is 180°F), allowing the inlet temperature to fall to its specified minimum before drawing from storage, and extending the utility of the storage system. The temperature drop through the user device is assumed constant at 75°F, irrespective of the inlet temperature. Thus, the design condition for the user device is 180°F inlet, 105°F outlet. The slightly larger heat exchanger surfaces (and costs) are compensated by the reduction in required storage volume.

If the demand increases above the point where bypass flow has decreased the inlet temperature to 180°F, additional water will be drawn from the hot water store and store will start to be emptied. The water through the bypass line will also increase. The relative flow rates from the hot water tank and through the bypass line are adjusted such that the inlet temperature to the district heating system is maintained at the minimum allowable distribution inlet temperature.

When the store empties, the flow rate across the bypass line must rise to equal the difference between the distribution system demand flow and the pipeline flow. With the store empty, the large bypass flow would reduce the temperature of water entering the distribution system below the minimum allowable distribution inlet temperature. To maintain the proper distribution inlet temperature, the backup system is designed to operate in a topping mode, adding just sufficient energy to the distribution water to maintain the minimum inlet temperature.

The advent of decreased demand in any of the above operating modes tends to reverse the above described system response.

6.2 DISTRICT HEATING SYSTEM OPERATING AND SIZING COMPUTER CODE – DHOPS

A computer code to simulate the operation of the aluminum plant waste heat recovery district heating system described in the previous section requires over 40 separate parameters (not including such essentially fixed parameters as the cost equation variables) to completely size and define the district heating system's operation and economics. The major district heating system variables are listed in Table 5. The DHOPS computer code, shown in block diagram form in Figure 21, was written to allow evaluation of the effects of the various parameters on the district heating based upon real hour-by-hour weather data. The basic DHOPS computer code assumptions are listed in Table 6.

The DHOPS computer program consists of four major subroutines – sizing, costing, operations, and economics. The sizing subroutine calculates the sizes and/or determines the operational parameters of the following system components based upon the various input parameters:

Table 5
MAJOR SYSTEM TRADEOFF VARIABLES

- TRANSMISSION PIPE SIZE AND FLOW RATE
- PLANT HEAT EXCHANGER EFFICIENCY AND PRESSURE DROP
- USER HEAT EXCHANGER TEMPERATURE DROP
- STORE SIZE
- CENTRAL/LOCAL FOSSIL FUEL TOPPING
- ENERGY COST ESCALATION
- DEMAND DENSITY
- NUMBER OF USERS
- TYPE OF USER

V03056

DHOPS
DISTRICT HEATING, OPERATION AND SIZING COMPUTER CODE
BLOCK FLOW DIAGRAM

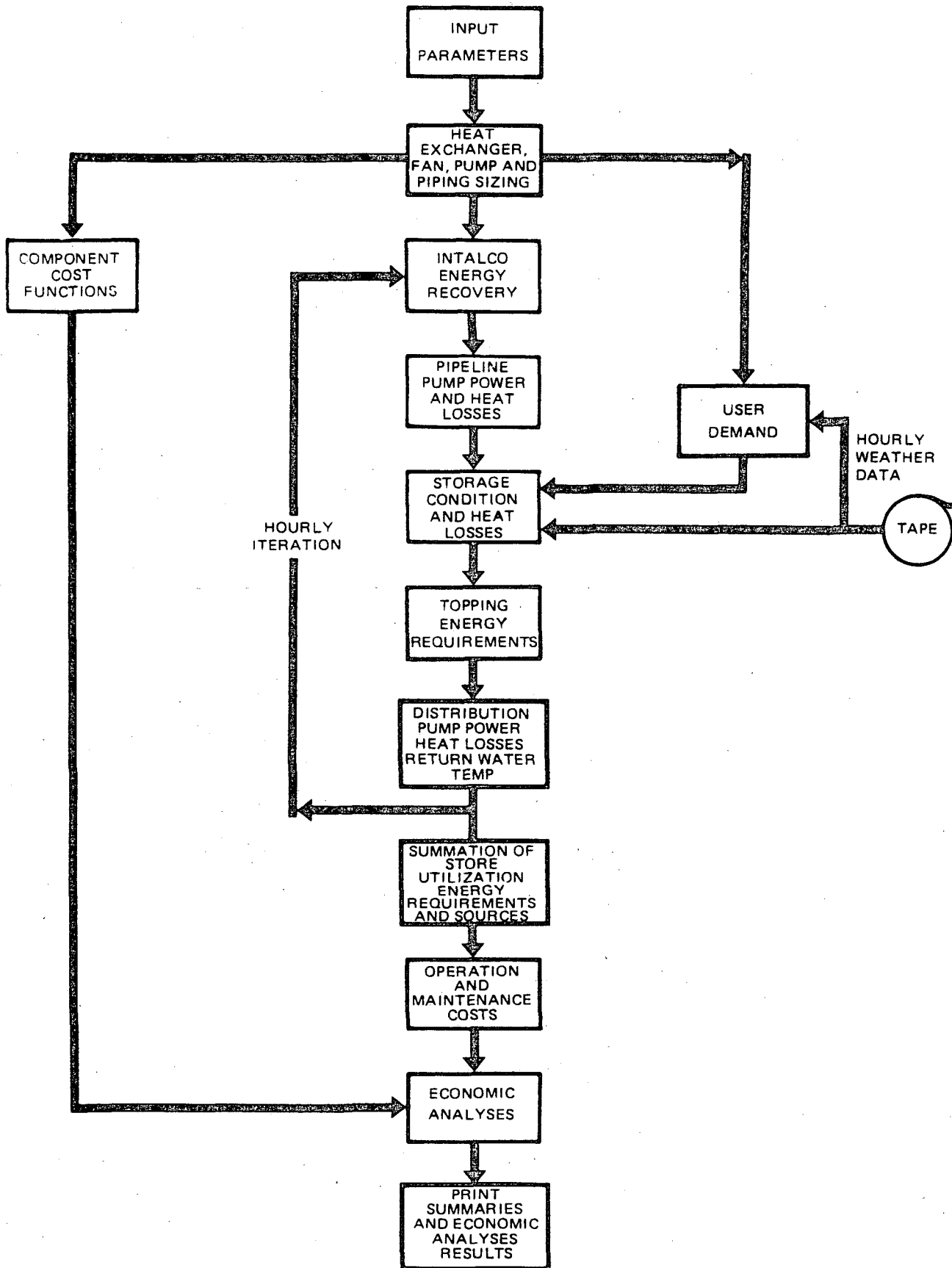


Table 6
MAJOR PROGRAM ASSUMPTIONS

- **CONSTANT SOURCE TEMPERATURE OF 260°F BASED UPON MEASURED TEMPERATURES AT INTALCO PLANT**
- **WEATHER TAPE INPUT FOR BELLINGHAM AREA**
- **ENERGY DEMAND PROFILES FOR BELLINGHAM BASED UPON WEATHER AND NATURAL GAS HISTORICAL DATA**
- **FOSSIL FUEL TOPPING FOR PEAK DEMANDS**
 - **CENTRAL BACKUP SUBSYSTEM**
 - **INDIVIDUAL USER SUBSYSTEM**
- **DISTRICT HEAT TRANSMISSION AND DISTRIBUTION SUBSYSTEM COST (BROOKHAVEN REPORT BNL-50516)**
- **STORAGE SUBSYSTEMS, HEAT EXCHANGER, AND OTHER COMPONENT COSTS BASED UPON MANUFACTURER CONTACTS AND STANDARD COST ESTIMATION DOCUMENTS AND PROCEDURES**
- **CURRENT FOSSIL FUEL COSTS BASED UPON LOCAL RATES**
- **GENERAL INFLATION RATE 5% PER YEAR**
- **LABOR COST INFLATION RATE 6% PER YEAR**
- **FUEL PRICE ESCALATION EXAMINED PARAMETRICALLY**
- **ERDA/EPRI REQUIRED REVENUE METHODOLOGY – ERDA/EPRI/JPL – JPL 5040-29**
- **30-YEAR PLANT LIFE**

1. Distribution system
2. Backup/topping system
3. Fossil fuel storage tanks
4. Waste heat recovery heat exchanger
5. User hot water and space heater heat exchangers
6. Transmission pipeline (pressure drop only)

The costing subroutine determines the cost of each of the system hardware components. Figure 22 shows a typical output from this subroutine. The costing equations were based upon the cost information reference shown in Table 7 and calculates various components in 1977 dollars.

The economics subroutine takes the total capital cost data calculated by the costing subroutine and the operational cost data (topping fuel requirements, electrical power requirements, system operation and maintenance costs), and the district heating system economic input parameters (these include fuel and energy costs, energy and price escalation rates, start of system operation, plant life and capital costs), and escalates them according to their appropriate escalation rate to the start of plant operation. The subroutine then calculates a year-by-year cash flow analysis over the economic life of the system. The cash flow analysis includes the effect of inflation and differing escalation rates on each of the cash flow component terms. On the basis of the cash flow analysis, the subroutine calculates the following economic parameters:

1. Net present value
2. Internal rate of return
3. Average return on investment in inflating dollars
4. Average return on investment in constant dollars
5. Average fossil fuel energy costs in inflating dollars
6. Average fossil fuel energy costs in constant dollars
7. Average supplied energy costs in inflating dollars
8. Average supplied energy cost in constant dollars
9. Levelized energy cost

Some of the more useful of these various economic parameters are discussed in more detail in paragraph 7.2.

Depending upon the requested print format, the economic subroutine will print the year-by-year cash flow and/or the above standard economic parameters. Figure 23 shows a typical output of this subroutine.

The year of the DHOPS program is the district heating operations subroutine. The operations subroutine models the system operation in an incremental time mode. That is, for a given point in time, the subroutine determines the overall system operation (user

CAPITAL COST FACTORS DOLLARS (1977)			
TRANSMISSION PIPELINE			
PIPE	5.89E+06	PUMPS	4.22E+04
TOTAL	5.9321E+06		
ALUMINUM PLANT HEAT EXCHANGERS			
HEAT EXCHANGER	4.39E+06	FANS	1.41E+05
PUMPS	4.96E+03	PLANT FACTOR	1.5
TOTAL	5.5935E+06		
STORAGE			
TANKS (2 EACH)	.0	INSULATION	.0
COST FACTOR	1.2		
TOTAL	.0		
BACKUP AND TOPPING SYSTEM			
BOILERS	5.58E+05	FUEL TANK	1.38E+05
FUEL	3.14E+05	COST FACTOR	1.2
TOTAL	1.194E+06		
DISTRIBUTION SYSTEM			
INSTALLED PIPING AND VALVES			
SQUARE MILES	2.71	AT	5.69E+06 DOLLARS/SQ MILE
TOTAL	1.5427E+07		
ENGINEERING AND ADMINISTRATION			
TOTAL	3.5175E+06		
TOTAL SYSTEM CAPITAL COST - 3.282963E+07			
USE IN CONNECTION			
CONNECTION	2.00E+06	RETROFIT	3.50E+06
TOTAL	5.500E+06		
TOTAL CAPITAL COST 3.832562E+07			

63

Figure 22

Table 7
COST INFORMATION REFERENCE LIST
PRIMARY SOURCES

<u>ITEM</u>	<u>SOURCES</u>
<u>TRANSMISSION PIPELINE</u>	
PIPE AND PIPE INSTALLATION	a. BROOKHAVEN NATIONAL LABORATORY – BNL 50516 b. PERSONAL COMMUNICATIONS WITH WHATCOM PLANNING COMMISSION STAFF AND THE BELLINGHAM ENGINEERING DEPARTMENT
PUMPS	BATTELLE, PACIFIC NORTHWEST LABORATORIES – BNWL-2208
<u>ALUMINUM PLANT HEAT EXCHANGERS</u>	
HEAT EXCHANGERS	GUTHERIE, K. M., PROCESS PLANT ESTIMATING EVALUATION AND CONTROL, CRAFTSMAN BOOK COMPANY*, 1974
FANS	Ibid ABOVE
PLANT FACTOR	RRC ENGINEERING ESTIMATE BASED UPON C. H. CHILTON, "CHEM. ENG." 56, No. 6, 9, 1949
<u>STORAGE</u>	
TANKS	a. GUTHERIE, K. M., PROCESS PLANT ESTIMATING EVALUATION CONTROL*, b. PERSONAL COMMUNICATIONS WITH LOCAL LARGE TANK FABRICATORS
INSULATION	PERSONAL COMMUNICATIONS WITH LOCAL INSULATION APPLICATION FIRMS
COST FACTOR	RRC ENGINEERING ESTIMATE BASED UPON C. H. CHILTON, "CHEM. ENG." 56, No. 6, 9, 1949

*COST DATA UPDATED BASED UPON PRICE INDEX DATA.

Table 7
COST INFORMATION REFERENCE LIST
PRIMARY SOURCES (Concluded)

<u>ITEM</u>	<u>SOURCES</u>
<u>BACKUP AND TOPPING SYSTEM</u>	
BOILERS	GUTHERIE, K. M., PROCESS PLANT ESTIMATING EVALUATION AND CONTROL *
FUEL TANK	Ibid ABOVE
FUEL	CURRENT LOCAL PRICES
COST FACTOR	RRC ENGINEERING ESTIMATE BASED UPON C. H. CHILTON, "CHEM. ENG." 56, No. 6, 9, 1949
<u>DISTRIBUTION SYSTEM</u>	
INSTALLED PIPING AND VALVES	a. BROOKHANEN NATIONAL LABORATORY – BNL 50516 b. BELLINGHAM POPULATION CENSES DATA – VARIOUS SOURCES BATTELLE PACIFIC NORTHWEST LABORATORIES – BNWL-2208
ENGINEERING AND ADMINISTRATION (DURING CONSTRUCTION)	
<u>USER</u>	
CONNECTION	BROOKHANEN NATIONAL LABORATORIES – BNL 50516
RETROFIT	a. THE TRANE COMPANY b. RRC ENGINEERING COST ESTIMATE
<u>OPERATIONAL</u>	
ADMINISTRATION	a. BATTELLE PACIFIC NORTHWEST LABORATORIES – BNWL-2208 b. A. B. ATOM ENGRG FOR OAK RIDGE NATIONAL LABORATORY – ORNL/SUB/77/13502/2
MAINTENANCE	
FUEL AND POWER	CURRENT LOCAL PRICES
INSURANCE	ERDA/EPRI/JPL — JPL 5040-29

*COST DATA UPDATED BASED UPON PRICE INDEX DATA.

ECONOMIC ANALYSES

ASSUMPTIONS

CURRENT ENERGY COSTS (1977 DOLLARS)
 USER ENERGY COST (\$/THERM) 3.640 (CONSUMED AT 0.70 EFFICIENCY)
 FOSSTIL COOPER COST (\$/GAL) .3900 (NO.6 FUEL OIL CONSUMED AT 0.90 EFFICIENCY)
 PUMP AND FAN ENERGY COST (\$/KW-HR) .0200

PLANT LIFE (YEARS) 30.00 (START OF PLANT OPERATION = 1985)

AFTER TAX COST OF CAPITAL .0800

ESCALATION RATES

GENERAL INFLATION RATE/YEAR .0500
 LABOR ESCALATION RATE/YEAR .0600
 ENERGY ESCALATION RATE/YEAR .1000

TOTAL SYSTEM COSTS (1985) AT START OF SYSTEM OPERATION 5.5223E+07

YEAR	RETAIL FUEL	SALES	CAP. COSTS	OPERATION	BACKUP	LOAN INT	NET	LOANS	EQUIV. COSTS
1986	8.5829E-06	9.3871E+06	4.9053E+06	1.3582E+06	3.4990E+05	.0	2.6897E+06	.0	6.1014E-06
1987	9.4412E-06	1.0243E+07	4.9053E+06	1.4544E+06	3.8489E+05	.0	3.4845E+06	.0	6.2265E-06
1988	1.0265E-05	1.1257E+07	4.9053E+06	1.5675E+06	4.2337E+05	.0	4.3606E+06	.0	6.3623E-06
1989	1.1424E-05	1.2392E+07	4.9053E+06	1.6850E+06	4.6571E+05	.0	5.3264E+06	.0	6.5098E-06
1990	1.2566E-05	1.3621E+07	4.9053E+06	1.8122E+06	5.1224E+05	.0	6.3910E+06	.0	6.6701E-06
1991	1.3823E-05	1.4983E+07	4.9053E+06	1.9497E+06	5.6351E+05	.0	7.5842E+06	.0	6.8442E-06
1992	1.5205E-05	1.6481E+07	4.9053E+06	2.0987E+06	6.1986E+05	.0	8.8572E+06	.0	7.0336E-06
1993	1.6726E-05	1.8129E+07	4.9053E+06	2.2600E+06	6.8185E+05	.0	1.0282E+07	.0	7.2396E-06
1994	1.8398E-05	1.9942E+07	4.9053E+06	2.4347E+06	7.5003E+05	.0	1.1852E+07	.0	7.4638E-06
1995	2.0238E-05	2.1936E+07	4.9053E+06	2.6241E+06	8.2504E+05	.0	1.3582E+07	.0	7.7077E-06
1996	2.2262E-05	2.4138E+07	4.9053E+06	2.8295E+06	9.0754E+05	.0	1.5488E+07	.0	7.9733E-06
1997	2.4488E-05	2.6544E+07	4.9053E+06	3.0523E+06	9.9829E+05	.0	1.7587E+07	.0	8.2628E-06
1998	2.6937E-05	2.9197E+07	4.9053E+06	3.2940E+06	1.0981E+06	.0	1.9900E+07	.0	8.5777E-06
1999	2.9631E-05	3.2117E+07	4.9053E+06	3.5565E+06	1.2079E+06	.0	2.2447E+07	.0	8.9211E-06
2000	3.2594E-05	3.5329E+07	4.9053E+06	3.8414E+06	1.3287E+06	.0	2.5293E+07	.0	9.2955E-06
2001	3.5853E-05	3.8841E+07	4.9053E+06	4.1510E+06	1.4616E+06	.0	2.8344E+07	.0	9.7037E-06
2002	3.9438E-05	4.2748E+07	4.9053E+06	4.4875E+06	1.6078E+06	.0	3.1747E+07	.0	1.0149E-05
2003	4.3387E-05	4.7072E+07	4.9053E+06	4.8533E+06	1.7685E+06	.0	3.5695E+07	.0	1.0635E-05
2004	4.7720E-05	5.1725E+07	4.9053E+06	5.2511E+06	1.9454E+06	.0	3.9623E+07	.0	1.1164E-05
2005	5.2492E-05	5.6897E+07	4.9053E+06	5.6839E+06	2.1399E+06	.0	4.4168E+07	.0	1.1744E-05
2006	5.7742E-05	6.2587E+07	4.9053E+06	6.1548E+06	2.3539E+06	.0	4.9173E+07	.0	1.2376E-05
2007	6.3516E-05	6.8845E+07	4.9053E+06	6.6675E+06	2.5893E+06	.0	5.4683E+07	.0	1.3066E-05
2008	6.9807E-05	7.5730E+07	4.9053E+06	7.2258E+06	2.8483E+06	.0	6.0751E+07	.0	1.3820E-05
2009	7.6754E-05	8.3303E+07	4.9053E+06	7.8340E+06	3.1331E+06	.0	6.7431E+07	.0	1.4648E-05
2010	8.4540E-05	9.1693E+07	4.9053E+06	8.4967E+06	3.4464E+06	.0	7.4785E+07	.0	1.5544E-05
2011	9.2954E-05	1.0093E+08	4.9053E+06	9.2190E+06	3.7910E+06	.0	8.2881E+07	.0	1.6528E-05
2012	1.0204E-04	1.1098E+08	4.9053E+06	1.0007E+07	4.1701E+06	.0	9.1794E+07	.0	1.7605E-05
2013	1.1252E-04	1.2194E+08	4.9053E+06	1.0865E+07	4.5871E+06	.0	1.0161E+08	.0	1.8782E-05
2014	1.2377E-04	1.3416E+08	4.9053E+06	1.1802E+07	5.0459E+06	.0	1.1241E+08	.0	2.0070E-05
2015	1.3515E-04	1.4788E+08	4.9053E+06	1.2825E+07	5.5504E+06	.0	1.2430E+08	.0	2.1478E-05

NET PRESENT VALUE = 1.8125E+08

INTERNAL RATE OF RETURN = .1360

AVERAGE RETURN ON INVESTMENT = .0708

AVERAGE RETURN ON INVESTMENT (\$1985) = .2472

AVERAGE RETAIL ENERGY COST = 4.7041E-05

AVERAGE RETAIL ENERGY COST (\$1985) = 1.7380E-05

AVERAGE RETAIL ENERGY COST (\$1977) = 1.1763E-05

AVERAGE ENERGY COST = 1.0950E-05

AVERAGE EQUIVALENT ENERGY COST (\$1985) = 4.7850E-06

AVERAGE EQUIVALENT ENERGY COST (\$1977) = 3.2387E-06

LEVELIZED ENERGY COST TO USER (\$1977) = 6.6950E-06

demands, store volumes, temperatures, etc., based upon the results of the previous time increment). The program then increments time (by one hour) and goes through the calculation procedure again. This cycle is repeated continuously until the program covers the desired time period (generally 1 year).

During each calculation cycle, the operations subroutine does the following:

1. Based upon the hourly weather data and the user energy demand functions described in paragraph 6.3, calculates the total distribution network energy demand.
2. Calculates the distribution network water flow rate and the return line temperature, including distribution network heat losses.
3. Calculates the bypass line flow and both the inlet and outlet flow rates for the water storage tanks as well as the volume in each tank, the tank heat losses, and the tank water temperatures.
4. Determines if fossil fuel topping is required and calculates the fossil fuel demand, if any.
5. Calculates the transmission pipeline heat losses, water temperatures, and determines the pipeline phase lag (i.e., the amount of time it takes water in the pipeline to get from Intalco to Bellingham and vice versa; typically, this is on the order of several hours).
6. Calculates the amount of energy removed from the Intalco gas stream based upon the heat exchanger area and efficiency, and the return line water temperature.
7. Calculates the temperature of the water leaving Intalco.
8. Determines the fan and pump power and pump power demands.

If desired, the program will print out, by hour, by day or by week, the parameters shown in Figure 24 for an hourly printout.

At the end of the period of interest (usually 1 year), the program summarizes the operation of the district heating system and calculates the system operating costs. A typical summary printout is shown in Figure 25.

6.3 WEATHER AND DEMAND DATA

The weather and demand data functions are an integral part of the DHOPS computer code, and allow the computer code to evaluate the operation of the district heating system and the interaction of the component parts on an hour-by-hour basis with real (historical) weather data.

6.3.1 Weather Data

A set of magnetic data tapes containing hour-by-hour observations of the Bellingham weather (the observation station was located at the Bellingham Airport, approximately 2

HOURLY OPERATIONS SUMMARY										
DATE	HOUR	(65.-TAMB) DEG.F	DEMAND BTU/HOUR	HOT H2O BTU/HOUR	HEATING BTU/HOUR	STORE GALLONS	STORE DEG.F	PLANT BTU/HOUR	FUEL BTU/HOUR	TGASOUT DEG.F
1/30/50	0	47	1.62E+05	.0	1.62E+05	.0	209	1.17E+08	.0	189
1/30/50	1	48	1.66E+05	.0	1.66E+05	.0	205	1.08E+08	.0	194
1/30/50	2	48	1.66E+05	.0	1.66E+05	.0	210	1.13E+07	.0	253
1/30/50	3	49	1.70E+05	.0	1.70E+05	.0	216	1.83E+07	.0	249
1/30/50	4	50	1.74E+05	.0	1.74E+05	.0	216	7.24E+06	.0	256
1/30/50	5	50	1.74E+05	.0	1.74E+05	.0	216	*.71E+06	.0	263
1/30/50	6	51	1.78E+05	.0	1.78E+05	.0	216	*.65E+06	.0	263
1/30/50	7	52	1.82E+05	.0	1.82E+05	.0	216	*.67E+06	.0	263
1/30/50	8	51	2.37E+05	5.83E+04	1.78E+05	.0	216	*.66E+06	.0	263
1/30/50	9	50	2.32E+05	5.83E+04	1.74E+05	.0	216	*.65E+06	.0	263
1/30/50	10	49	2.28E+05	5.83E+04	1.70E+05	.0	216	*.60E+06	.0	263
1/30/50	11	48	2.24E+05	5.83E+04	1.66E+05	.0	216	*.61E+06	.0	263
1/30/50	12	48	2.24E+05	5.83E+04	1.66E+05	.0	216	*.61E+06	.0	263
1/30/50	13	46	2.16E+05	5.83E+04	1.58E+05	.0	216	*.61E+06	.0	263
1/30/50	14	46	2.16E+05	5.83E+04	1.58E+05	.0	216	*.62E+06	.0	263
1/30/50	15	46	2.16E+05	5.83E+04	1.58E+05	.0	216	*.62E+06	.0	263
1/30/50	16	46	2.16E+05	5.83E+04	1.58E+05	.0	216	*.62E+06	.0	263
1/30/50	17	47	2.20E+05	5.83E+04	1.62E+05	.0	216	*.62E+06	.0	263
1/30/50	18	48	1.66E+05	.0	1.66E+05	.0	216	*.62E+06	.0	263
1/30/50	19	48	1.66E+05	.0	1.66E+05	.0	216	*.63E+06	.0	263
1/30/50	20	49	1.70E+05	.0	1.70E+05	.0	216	*.67E+06	.0	263
1/30/50	21	52	1.82E+05	.0	1.82E+05	.0	216	*.67E+06	.0	263
1/30/50	22	53	1.86E+05	.0	1.86E+05	.0	216	*.67E+06	.0	263
1/30/50	23	55	1.94E+05	.0	1.94E+05	.0	216	*.66E+06	.0	263
1/31/50	0	55	1.94E+05	.0	1.94E+05	.0	216	*.65E+06	.0	263
1/31/50	1	56	1.99E+05	.0	1.99E+05	.0	216	*.65E+06	.0	263
1/31/50	2	60	2.15E+05	.0	2.15E+05	.0	216	*.65E+06	.0	263
1/31/50	3	63	2.27E+05	.0	2.27E+05	.0	216	*.64E+06	.0	263
1/31/50	4	63	2.27E+05	.0	2.27E+05	.0	216	*.62E+06	.0	263
1/31/50	5	56	1.99E+05	.0	1.99E+05	.0	216	*.61E+06	.0	263
1/31/50	6	58	2.07E+05	.0	2.07E+05	.0	216	*.62E+06	.0	263
1/31/50	7	56	1.99E+05	.0	1.99E+05	.0	216	*.64E+06	.0	263
1/31/50	8	56	2.57E+05	5.83E+04	1.99E+05	.0	216	*.63E+06	.0	263
1/31/50	9	55	2.53E+05	5.83E+04	1.94E+05	.0	216	*.63E+06	.0	263
1/31/50	10	52	2.41E+05	5.83E+04	1.82E+05	.0	216	*.58E+06	.0	263
1/31/50	11	47	2.20E+05	5.83E+04	1.62E+05	.0	216	*.59E+06	.0	263
1/31/50	12	46	2.16E+05	5.83E+04	1.58E+05	.0	216	*.60E+06	.0	263
1/31/50	13	45	2.12E+05	5.83E+04	1.54E+05	.0	216	*.62E+06	.0	263
1/31/50	14	44	2.16E+05	5.83E+04	1.58E+05	.0	216	*.62E+06	.0	263
1/31/50	15	47	2.20E+05	5.83E+04	1.62E+05	.0	216	*.63E+06	.0	263
1/31/50	16	45	2.12E+05	5.83E+04	1.54E+05	.0	216	*.62E+06	.0	263
1/31/50	17	46	2.16E+05	5.83E+04	1.58E+05	.0	216	*.62E+06	.0	263
1/31/50	18	46	1.58E+05	.0	1.58E+05	.0	216	*.63E+06	.0	263
1/31/50	19	50	1.74E+05	.0	1.74E+05	.0	216	*.63E+06	.0	263
1/31/50	20	53	1.86E+05	.0	1.86E+05	.0	216	*.68E+06	.0	263
1/31/50	21	58	2.07E+05	.0	2.07E+05	.0	216	*.66E+06	.0	263
1/31/50	22	58	2.07E+05	.0	2.07E+05	.0	216	*.65E+06	.0	263
1/31/50	23	60	2.15E+05	.0	2.15E+05	.0	216	*.63E+06	.0	263
2/ 1/50	0	58	2.07E+05	.0	2.07E+05	.0	216	*.63E+06	.0	263
2/ 1/50	1	58	2.07E+05	.0	2.07E+05	.0	216	*.63E+06	.0	263
2/ 1/50	2	61	2.19E+05	.0	2.19E+05	.0	216	*.63E+06	.0	263
2/ 1/50	3	63	2.27E+05	.0	2.27E+05	.0	216	*.63E+06	.0	263
2/ 1/50	4	62	2.23E+05	.0	2.23E+05	.0	216	*.62E+06	.0	263
2/ 1/50	5	61	2.27E+05	.0	2.27E+05	.0	216	*.61E+06	.0	263
2/ 1/50	6	62	2.23E+05	.0	2.23E+05	.0	216	*.62E+06	.0	263
2/ 1/50	7	64	2.31E+05	.0	2.31E+05	.0	216	*.61E+06	.0	263

DISTRICT HEATING OPERATIONS SUMMARY

TOTAL ENERGY SUPPLIED	5.6905E+11	BTUS
RESIDENTIAL	5.6905E+11	BTUS
LARGE COMMERCIAL	.0	BTUS
SMALL COMMERCIAL	.0	BTUS

ENERGY SOURCES

ALUMINUM PLANT	100	PERCENT
FOSSIL FUEL	.04	PERCENT

SYSTEM LOAD FACTORS

DESIGN	.72
ANNUAL	.36
PEAK DEMAND	1.8276E+08 BTUS/HOUR
PEAK FUEL DEMAND	5.2193E+07 BTUS/HOUR

STORE UTILIZATION

STORE FULL	7251 HOURS
STORE EMPTY	14 HOURS
STORE BEING UTILIZED	3461 HOURS
MAXIMUM PERIOD STORE EMPTY	10 HOURS
MAXIMUM PERIOD STORE FULL	3607 HOURS
MINIMUM STORE VOLUME	.0 GALLONS

OPERATING COST FACTORS-DOLLARS (1977)

ADMINISTRATION	7.00E+04	MAINTENANCE	2.74E+05
PUMPING POWER	1.84E+05	FUEL	7.41E+02 AT 2.89E-06 PER BTU
INSURANCE	6.85E+04	LOCAL TAXES	.0
STATE TAXES	.0	FEDERAL TAXES	.0
TOTAL OPERATING COSTS	5.9536E+05		

miles from the center of Bellingham) was procured from the NOAA National Climatic Center, Applied Climatology Division. The tape covered a period from January 1948 through December 1958, and from January 1974 through December 1976. Hour-by-hour weather data was not available for the years from 1959 to 1973.

A small computer program was developed and was used to determine from the weather tapes the total heating degree hours for the Bellingham area by month. Heating degree hours are defined as the summation by hour of the difference between a 65°F reference temperature and the outdoor air temperature below 65°F. If the outdoor air temperature is above the 65°F reference temperature, the heating degree hours for that period are equal to zero. Restated mathematically, heating degree hours are defined as:

$$\text{Heating degree hours} = \sum_{\text{Hour} = 1}^{\text{Hour} = n} (65^{\circ}\text{F} - T_i)^*$$

where:

- n = last hour of the period of interest
- T_i = outside air temperature, °F, ith hour

The number of heating degree hours in a given time period is approximately linearly proportional to the space heating requirements for the same period.

From the heating degree hour data, a typical and two extreme weather years were identified. The typical and extreme weather years were based upon a heating season starting on July 1, and running through June 30 of the following year. Figure 26 presents a comparison of the heating degree hours for selected typical weather year (1974 to 1975 heating season), and the 30-year averaged heating degree hours for the same months. The total annual heating degree hours for selected typical heating season (1974 to 1975) are within 1/4% of the 30-year averaged heating degree requirements.

The typical and extreme heating seasons for the Bellingham area are shown in Figure 27.

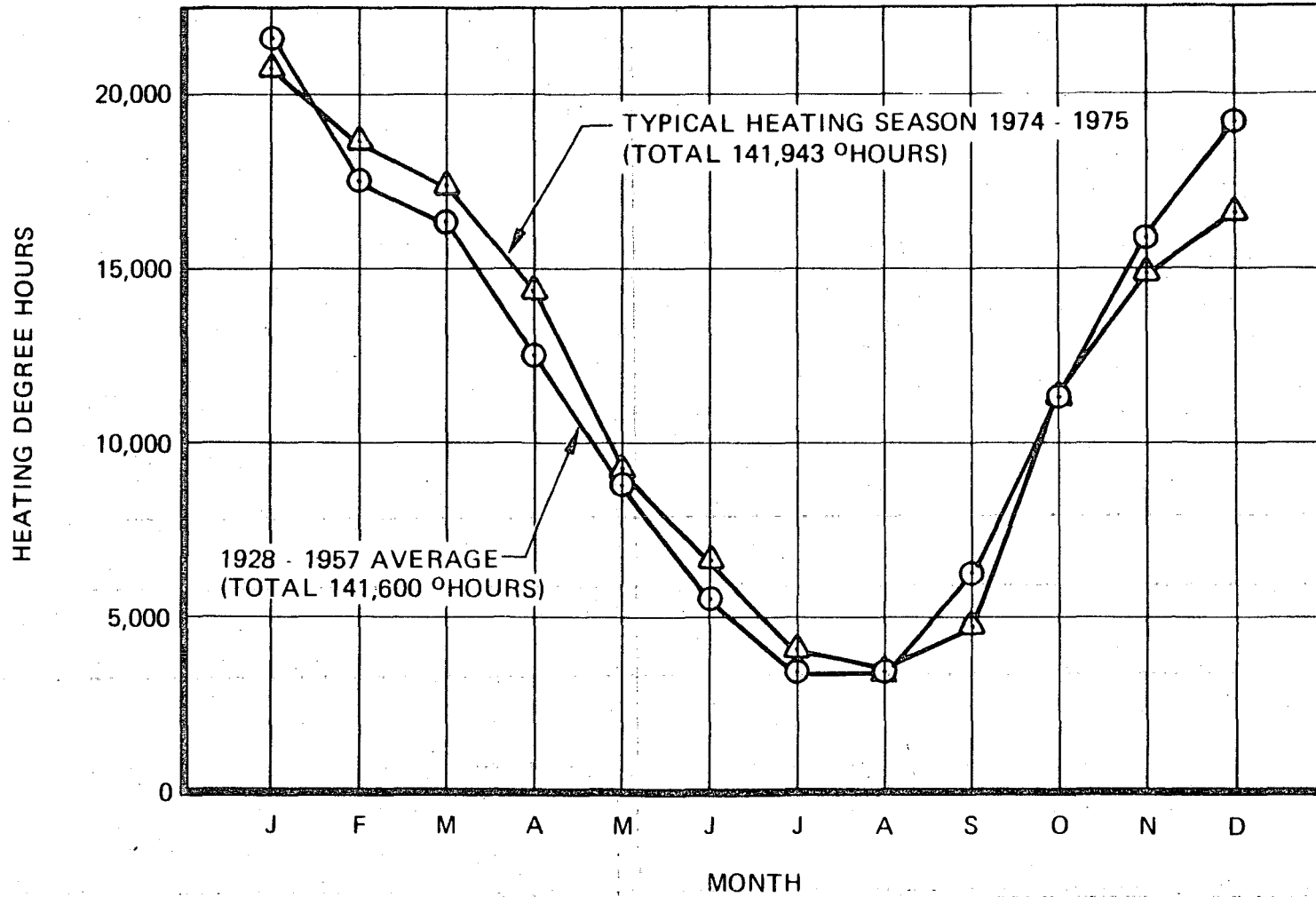
6.3.2 User Demand

The user energy demand from the district heating system consists of two separate factors: space heating demands, and hot water demands. The space heating demand is primarily a function of the weather, or more specifically, the difference between the outside air temperature and inside air temperature.

The hot water heating energy demands are primarily functions of the day of the week and the time of the day, and vary only slightly with the time of year and the weather.

*If the quantity (65°F - T_i) is negative, the quantity for purposes of summation is assumed to be equal to zero.

COMPARISON OF AVERAGE AND SEASONS SELECTED TYPICAL HEATING DEGREE HOURS VS. MONTH



TYPICAL AND EXTREME HEATING SEASONS HEATING DEGREE HOURS vs MONTH

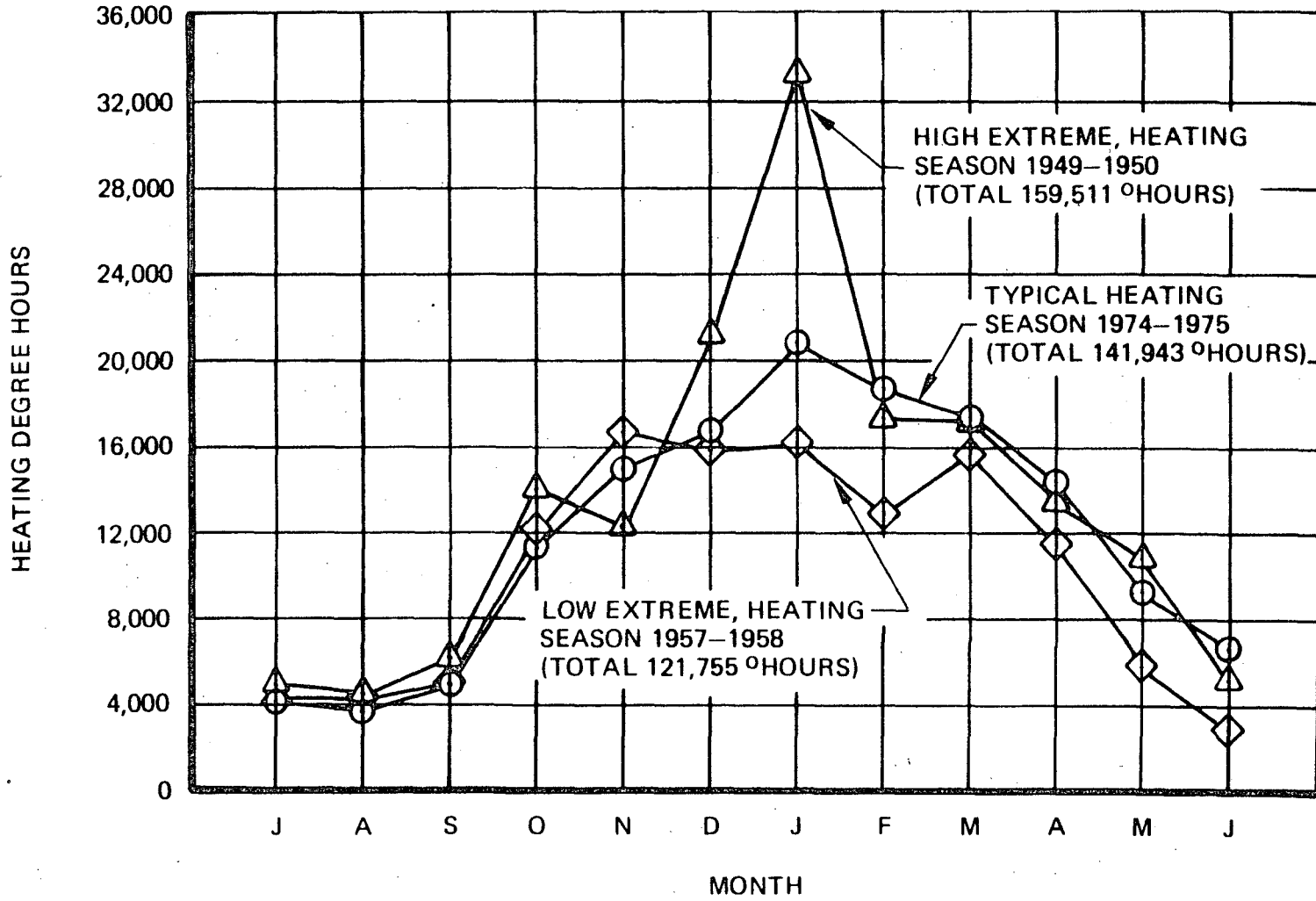
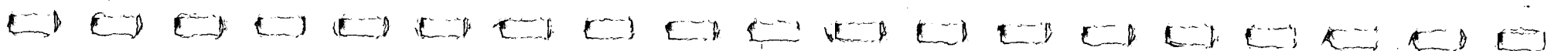


Figure 27



In order to estimate the space heating proportionally constant, K, and the hot water heating demands for average Bellingham potential district heating customers, information was gathered from the Bellingham natural gas supplier (Cascade Natural Gas Company) on natural gas consumption in Bellingham for three classes of users, large commercial, small commercial, and residential. The information supplied consisted of total natural gas consumption by user type per month for approximately 3 years. Linear regression curve fit analyses were performed using the natural gas data to develop user energy demand equations for each type of user. The natural gas consumption data and the calculated curve fits are presented in Figures 28, 29, and 30. A better fit of the residential energy demand data was achieved when the reference temperature was adjusted as a function of time as shown in Figure 29. The adjusted reference temperature corresponds to night-time thermostat setback of approximately 5°F.

Since the hot water heating energy demands are assumed to be independent of the space heating requirements, the average hot water heating energy demand would be shown on the natural gas energy demand plots as the energy demand, when the heating demand is equal to zero, i.e., when the monthly average heating degrees are equal to zero (Y intercept). The commercial water heating energy demands were assumed to be constant from 8:00 a.m. to 6:00 p.m., 7 days a week, and equal to zero at other hours. The residential water heating energy demands were assumed to be constant between 6:00 a.m. and 11:00 p.m., 7 days a week and equal to zero at other hours.

Additional accuracy in modeling the hot water demand-time function is not felt to be warranted, as the addition of the space heat demand will tend to mask the fine structure of the smaller hot water demand.

The natural gas energy demand data is based upon the therms of natural gas consumed by the space and hot water heaters of the user. Due to the efficiency losses of the space and hot water heaters, the actual energy demand of the user would be less than that shown in the natural gas energy demand plots. Assuming a conservative estimate of the efficiency of the space and hot water heaters of approximately 70% (based upon information supplied by Argonne National Laboratories, gas heater conversion efficiencies range from 60 to 67%), the actual energy demand required by the various losses of users becomes:

Large Commercial

Space heating demand per user, Btu/hr:

$$q_{scc} = (65^{\circ}\text{F} - T_{amb}) 49,000 - 330,540 \quad \text{for } (65^{\circ}\text{F} - T_{amb}) \geq 12$$

$$q_{scc} = (65^{\circ}\text{F} - T_{amb}) 20,895 \quad \text{for } (65^{\circ}\text{F} - T_{amb}) < 12$$

Water heating demand per user, Btu/hr:

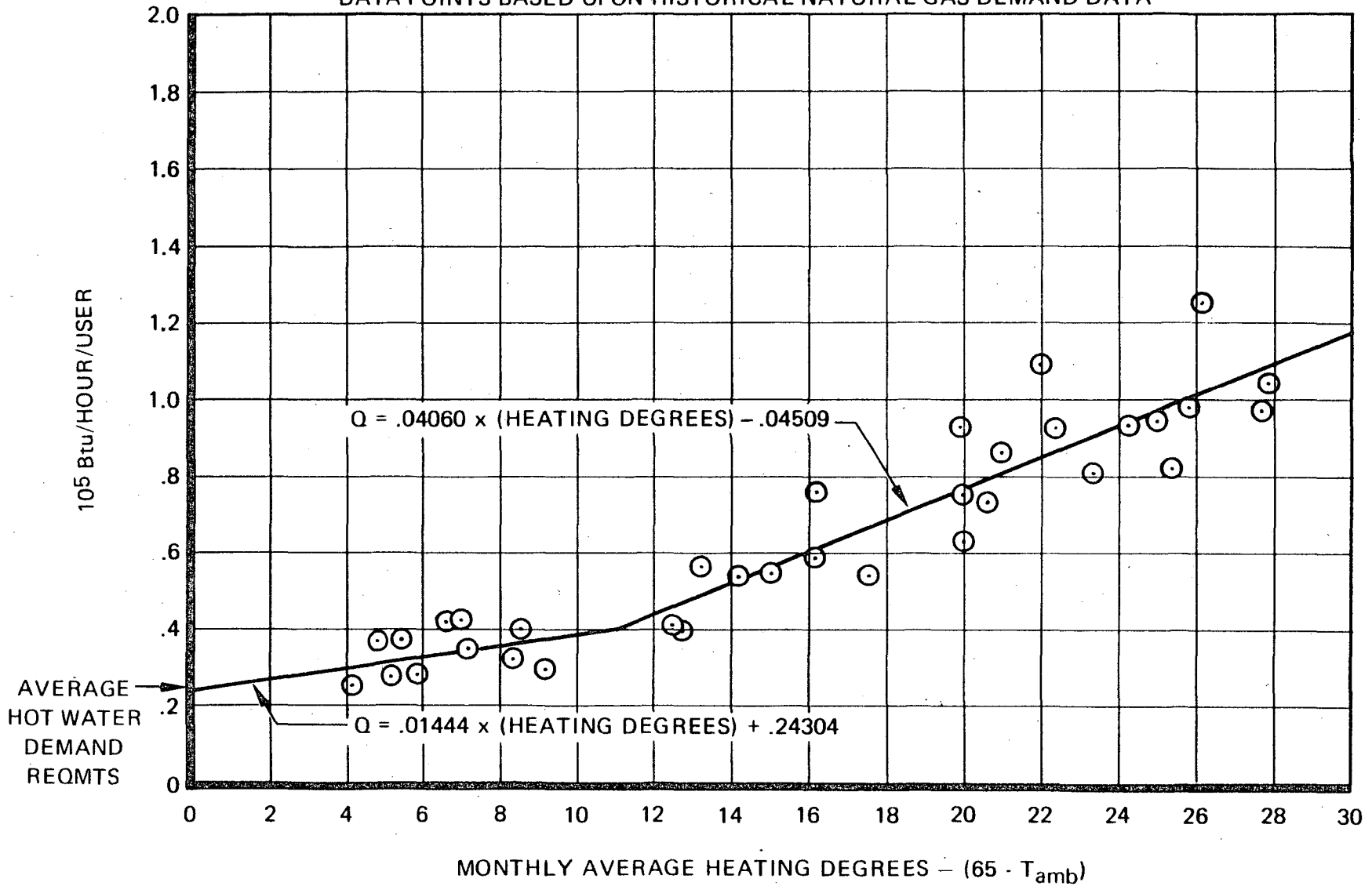
$$q_{wcc} = 1,050,000 \quad \text{from 8:00 a.m. to 6:00 p.m.}$$

$$q_{wcc} = 0.0 \quad \text{from 6:00 p.m. to 8:00 a.m.}$$

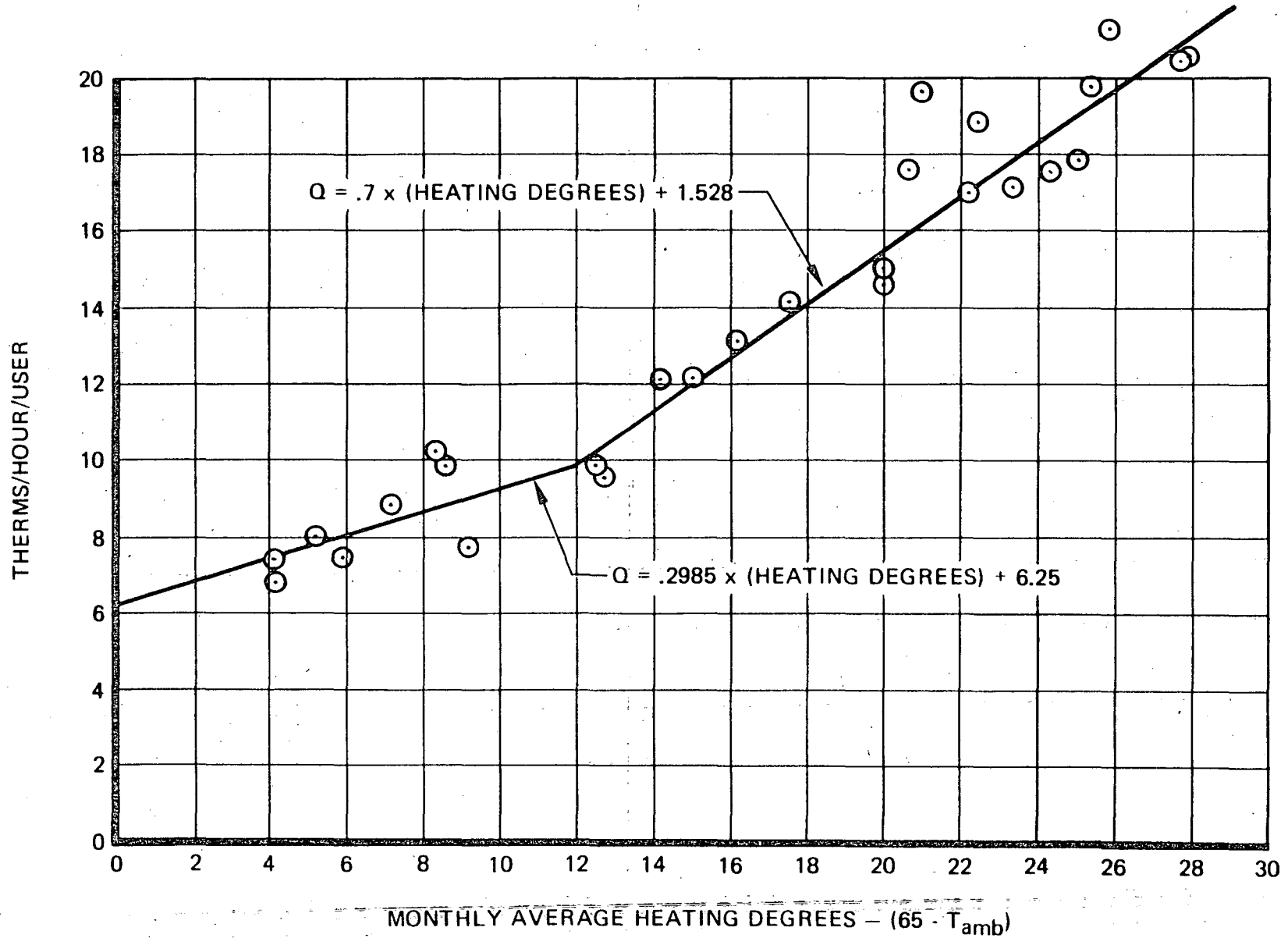
SMALL COMMERCIAL ENERGY DEMAND VS. HEATING DEGREES

1974 - 1976

DATA POINTS BASED UPON HISTORICAL NATURAL GAS DEMAND DATA



LARGE COMMERCIAL ENERGY DEMAND VS. HEATING DEGREES



RESIDENTIAL ENERGY DEMAND VS. HEATING DEGREES

1974 - 1976

DATA POINTS BASED UPON HISTORICAL BELLINGHAM NATURAL GAS DEMAND DATA

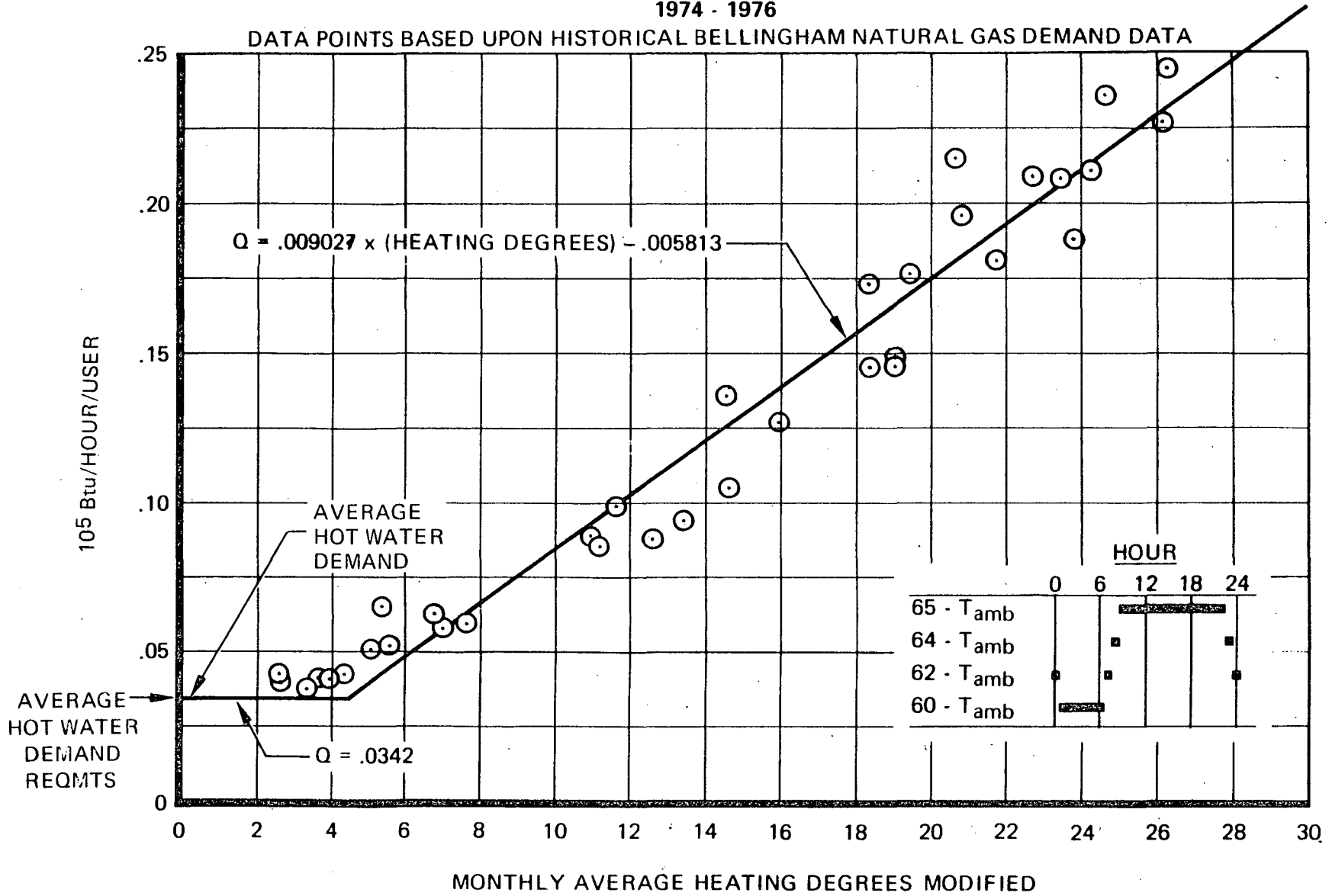


Figure 30

Small Commercial

Space heating demand per user, Btu/hr:

$$q_{ssc} = (65^{\circ}\text{F} - T_{\text{amb}}) 2,842 - 20,109 \quad \text{for } (65^{\circ}\text{F} - T_{\text{amb}}) \geq 11$$

$$q_{ssc} = (65^{\circ}\text{F} - T_{\text{amb}}) 1,010.8 \quad \text{for } (65^{\circ}\text{F} - T_{\text{amb}}) < 11$$

Water heating demand per user, Btu/hr:

$$q_{wsc} = 40,880 \quad \text{from 8:00 a.m. to 6:00 p.m.}$$

$$q_{wsc} = 0.0 \quad \text{from 6:00 p.m. to 8:00 p.m.}$$

Residential

Space heating demand per user, Btu/hr:

$$q_{se} = (T_{\text{ref}} - T_{\text{amb}}) 631.4 - 1,987.3 \quad \text{for } (T_{\text{ref}} - T_{\text{amb}}) \geq 4.4$$

$$q_{se} = 0.0 \quad \text{for } (T_{\text{ref}} - T_{\text{amb}}) < 4.4$$

Water heating demand per user, Btu/hr:

$$q_{wr} = 3,379.6 \quad \text{from 6:00 a.m. to 11:00 p.m.}$$

$$q_{wr} = 0.0 \quad \text{from 11:00 p.m. to 6:00 a.m.}$$

Daily demand curves illustrating the three types of user's combined space and water heating are presented in Figures 31, 32, and 33. The example day shown in January 31, 1950.

6.4 USER DENSITY ESTIMATES

The cost of the district heating distribution system is a strong function of the design energy demand density (Btu/hr/mile²). The design energy demand is a function of the type of user being served, how close the users are spaced to one another (area per user), and the coldest ambient temperature that the district heating system is designed to meet (system design temperature) under normal operating conditions.

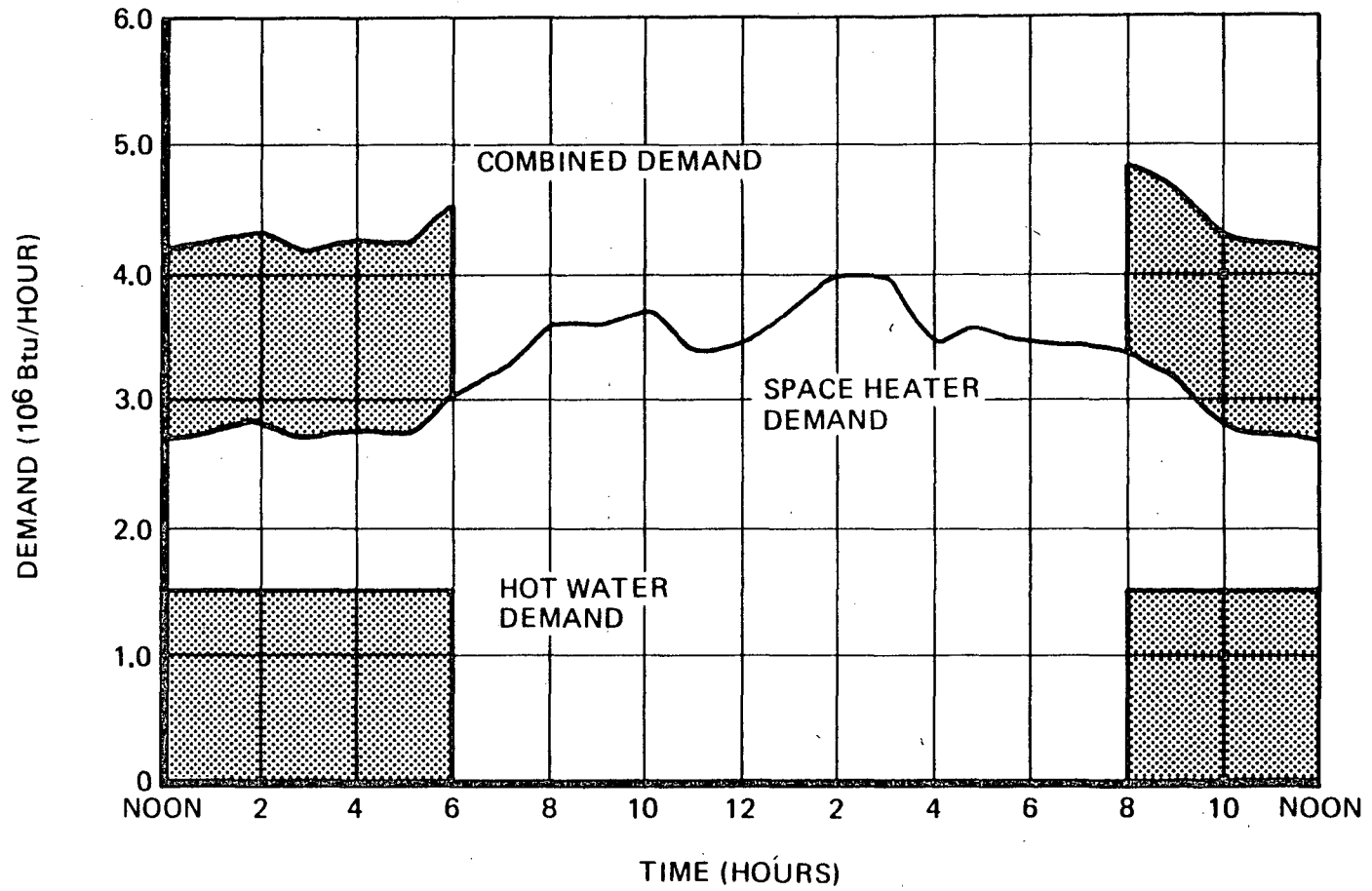
Based upon a review of historical Bellingham weather data back to 1910, a system design temperature of 0°F was selected for the backup and topping system. This was a centrally located fossil fuel fired plant. A second topping option incorporating electrical backup heaters in the user's facility is described in paragraph 6.5.2. For that system, the combined ambient temperature capability of the district heating system and the user electrical topping device was 0°F.

The area per user was estimated based upon census data supplied by the Bellingham Planning Department, and information supplied by Cascade Natural Gas. The estimated average area per user is:

- a. Residential - 0.000388 miles²/user
- b. Small commercial - 0.001717 miles²/user
- c. Large commercial - 0.0282 miles²/user

Included in the average area per user estimates are the area of streets, parks, etc.

LARGE COMMERCIAL 1/31/50



RESIDENTIAL
1/31/50

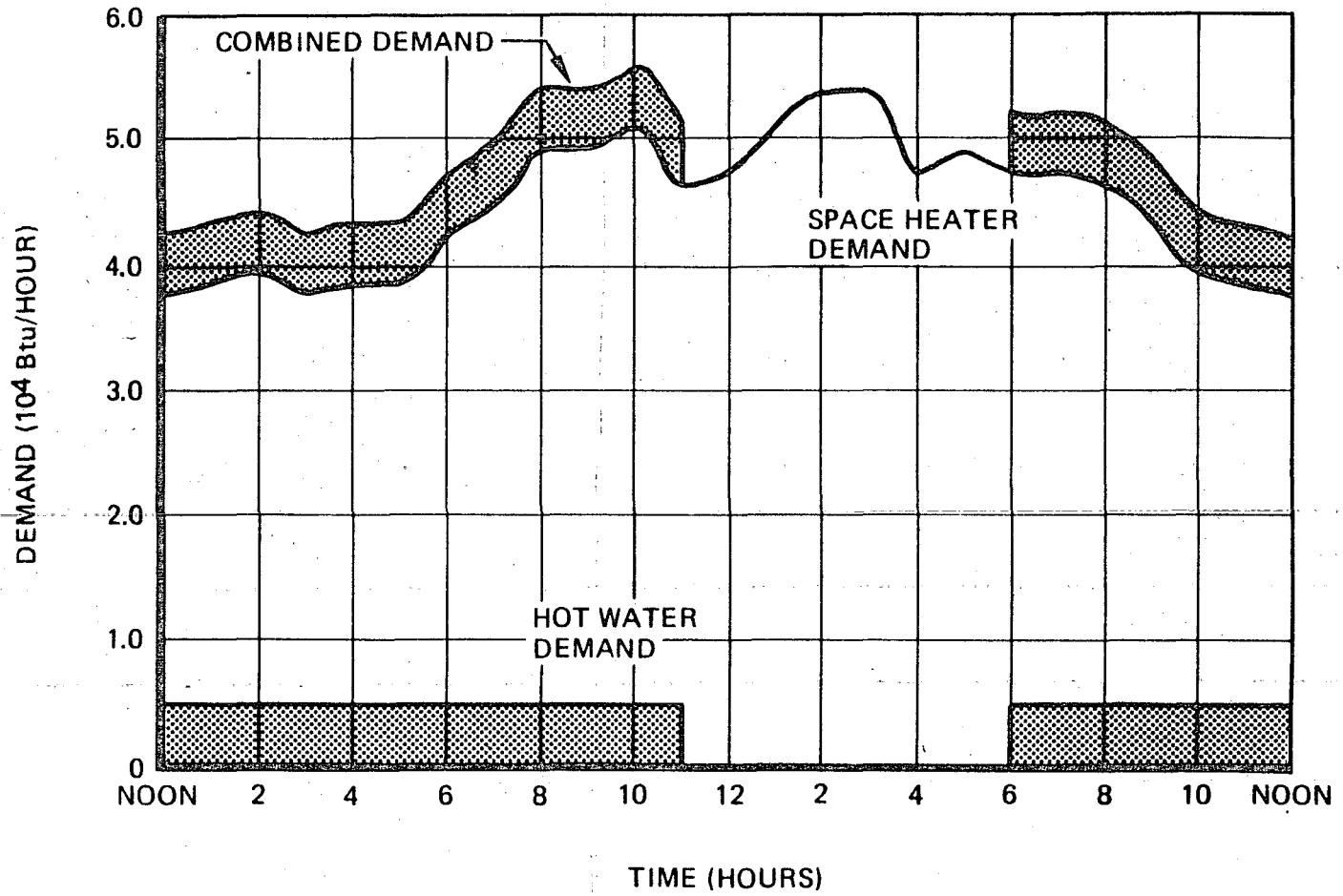
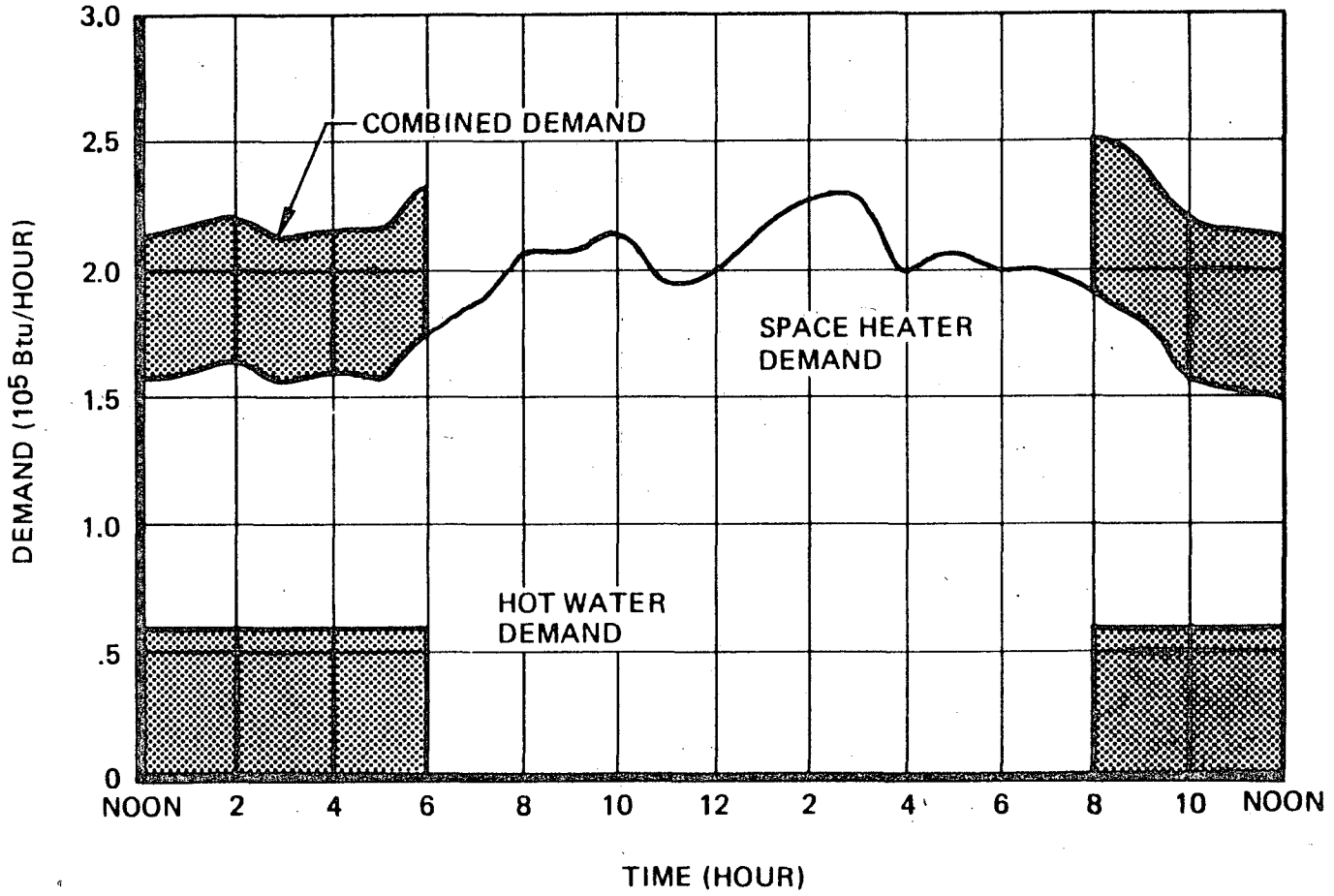


Figure 32

SMALL COMMERCIAL
1/31/50



6.5 ANALYSIS RESULTS

The results presented in this section are based on the DHOPS computer model described in paragraph 6.2. Over 500 separate cases were run to examine the effects of different system configurations, design requirements, and annual weather conditions.

Overall system optimization of the primary system variables was performed using both bi-variant and multi-variant techniques. Multi-variant optimization was performed by means of a Sandia Laboratory supplied Simplex method optimizer computer code which was used with the DHOPS program via an interface computer program.

6.5.1 Baseline District Heating System Analysis Results

The analysis results described in this section are based upon the baseline district heating system configuration shown schematically in Figure 20 and described in paragraph 6.1.

While the effects of the various types of users on the overall system operation and optimization were examined during the course of the Task V analyses, the results presented in the following sections are presented only in terms of an equivalent number of residential customers. This was done to provide a more direct reader-relatable parameter than could be achieved by means of a composite parameter, including the relative percentages of small commercial, large commercial, and residential customers that would be connected to the system. For the optimum system configuration, there is no significant difference in overall system configuration or economics between a given number of residential customers, and an equivalently sized (based upon annual energy demand requirements) composite mixture of the various user types (for the optimum district heating system configurations, the thermal energy store is large enough to damp out the effect of the commercial users greater diurnal cyclic demand).

For each size (number of users) district heating system, there is a different optimum, from an overall system standpoint, of sizes for each of the various system components. For the purposes of this analysis, the overall system optimums are based upon minimizing the cost of the energy supplied to the user (\$/Btu) over the life of the system.

The heat exchanger configuration (tube spacing, tube diameter, and cross-sectional flow area, etc.) and the heat exchanger surface area must be optimized against their effects on the pressure drop across the heat exchanger (fan power requirements), heat exchanger costs, and the amount (and value) of the recovered energy.

Likewise, the transmission line flow rate and pipe size must be optimized against the pumping power requirements, pipe cost, and value of the energy being transported.

The cost of each increment of thermal energy storage added to the system must be balanced against the decrease in fossil topping fuel requirements (increase in the net displaced energy).

For example, Figure 34 shows the effect of store capacity on the relative cost of energy supplied to the user over the lifetime of the plant. The upward breaks in the Figure 34 curves are the result of the store being oversized and not being cycled completely. The excess store capacity does not provide any significant increase in the amount of energy recovered from the aluminum plant, but increases the initial capital cost, and hence the cost of energy supplied to the user.*

Figure 35 shows the cost breakdown for optimized (the location of the minimums in Figure 34) district heating system serving various number of residential users. The net displaced energy for these district heating systems is presented in Figure 36.

6.5.2 Home Topping Analysis Results

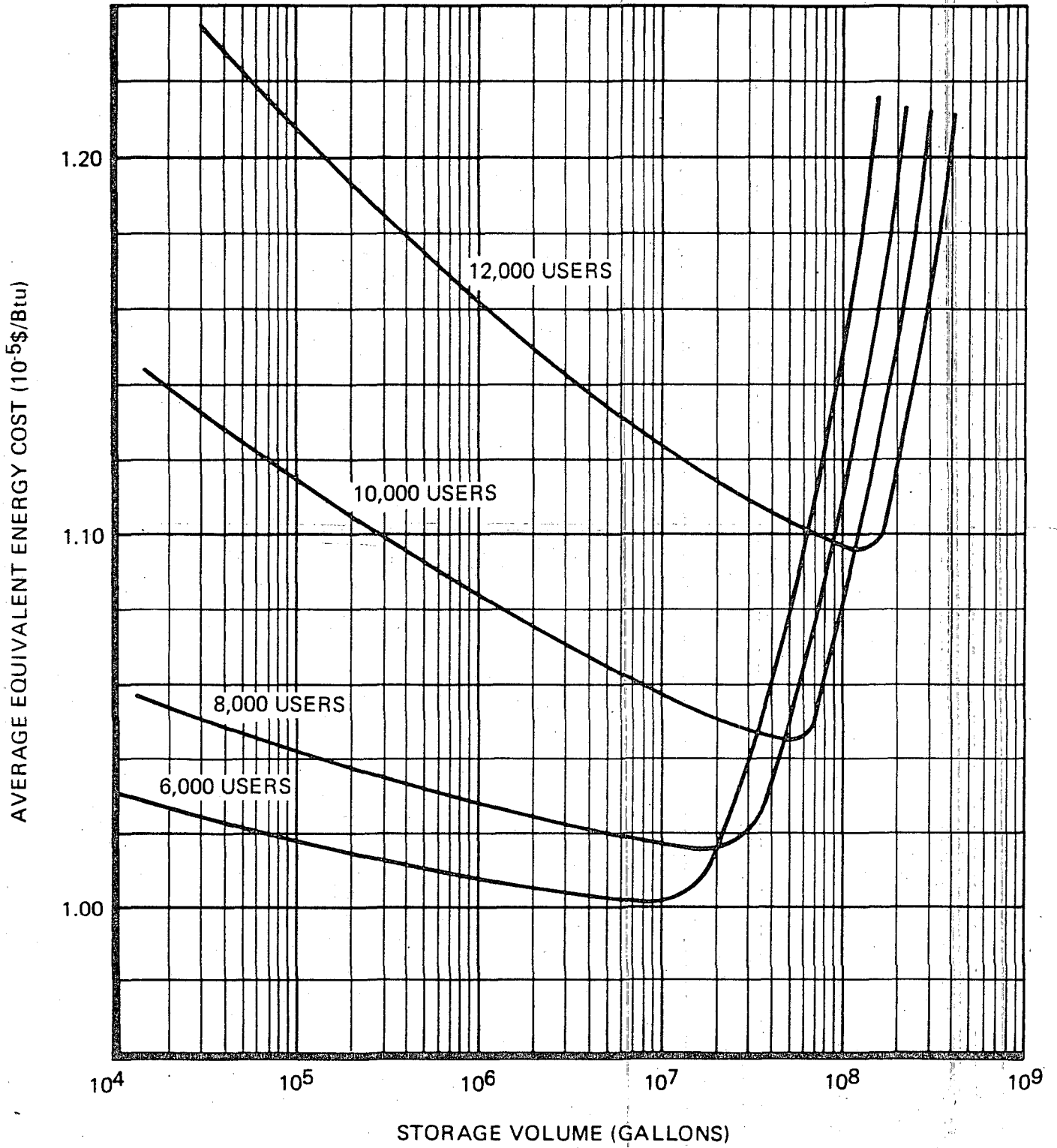
Without any topping capabilities at the user end of the district heating system, the distribution network must be sized to be able to supply the maximum energy demand on cold days. This means the distribution network pipes are oversized except for a few hours every 10 years or so, when an extremely cold day occurs. If some fraction of the peak energy demand could be supplied by the user on those days, the distribution piping network could be made correspondingly smaller and cheaper. Since the distribution piping system is a large fraction of the overall system cost, reducing the district heating system's peak demand could potentially significantly reduce the overall district heating system cost.

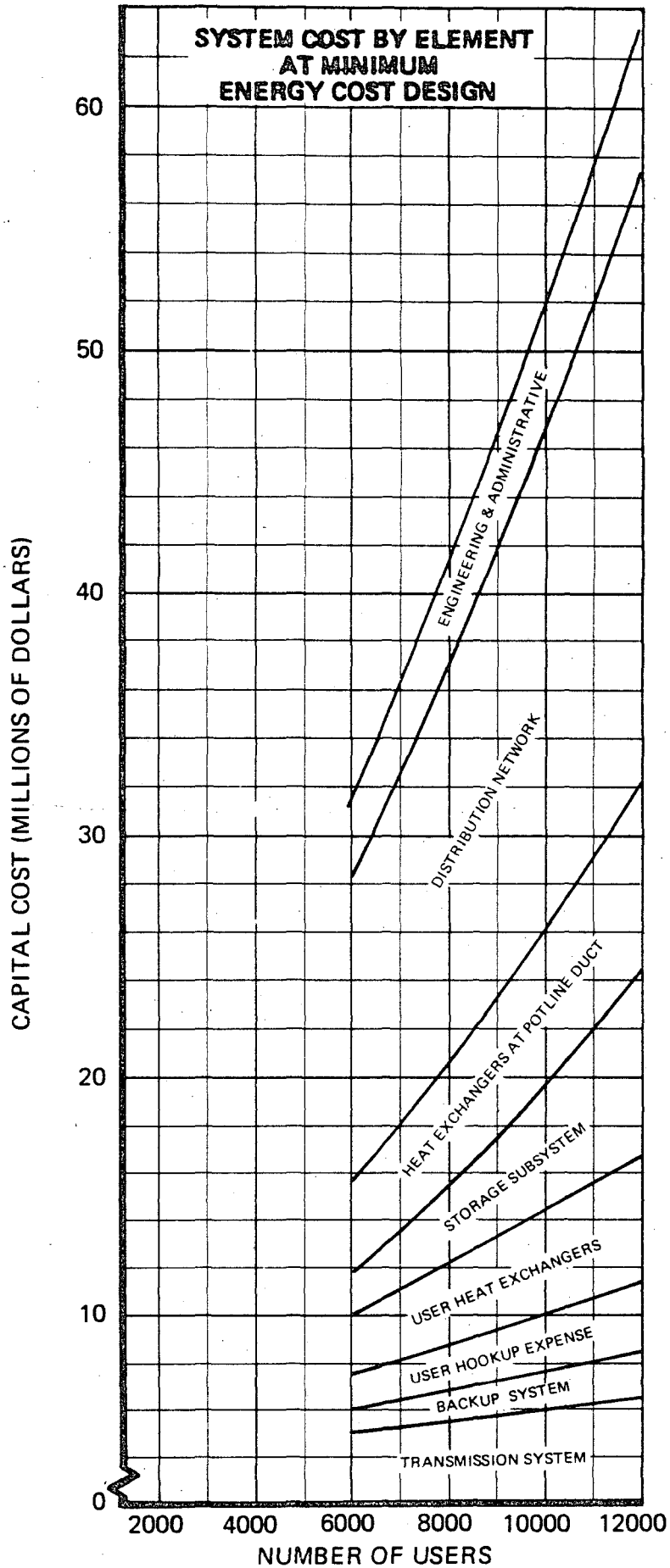
Several analyses were made of this concept, shown schematically in Figure 37. These analyses indicated that such a scheme might result in a potential system cost decrease on the order of 10%, at the expense of a significant increase in system complexity, and a slight reduction in the amount of energy displaced by the system.

In addition to the system complexity problems, there are other questionable areas with the concept including the cost and availability of electrical power to meet those few extreme weather days.

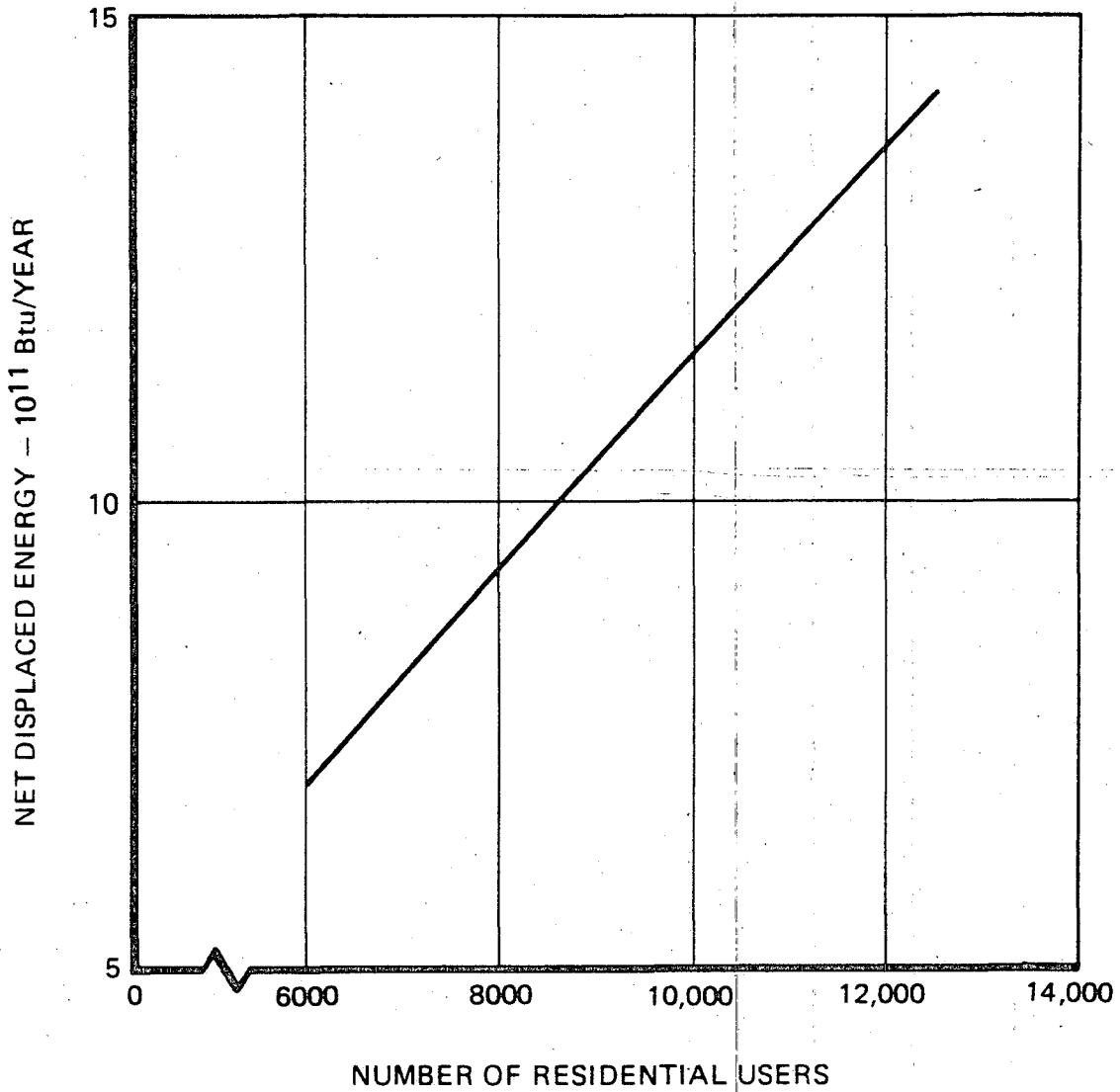
*The 12,000 user equivalent, 10^8 gal storage case is compared to conventional fossil fuel price in Figure 42.

EFFECT OF STORAGE VOLUME ON USER ENERGY COST

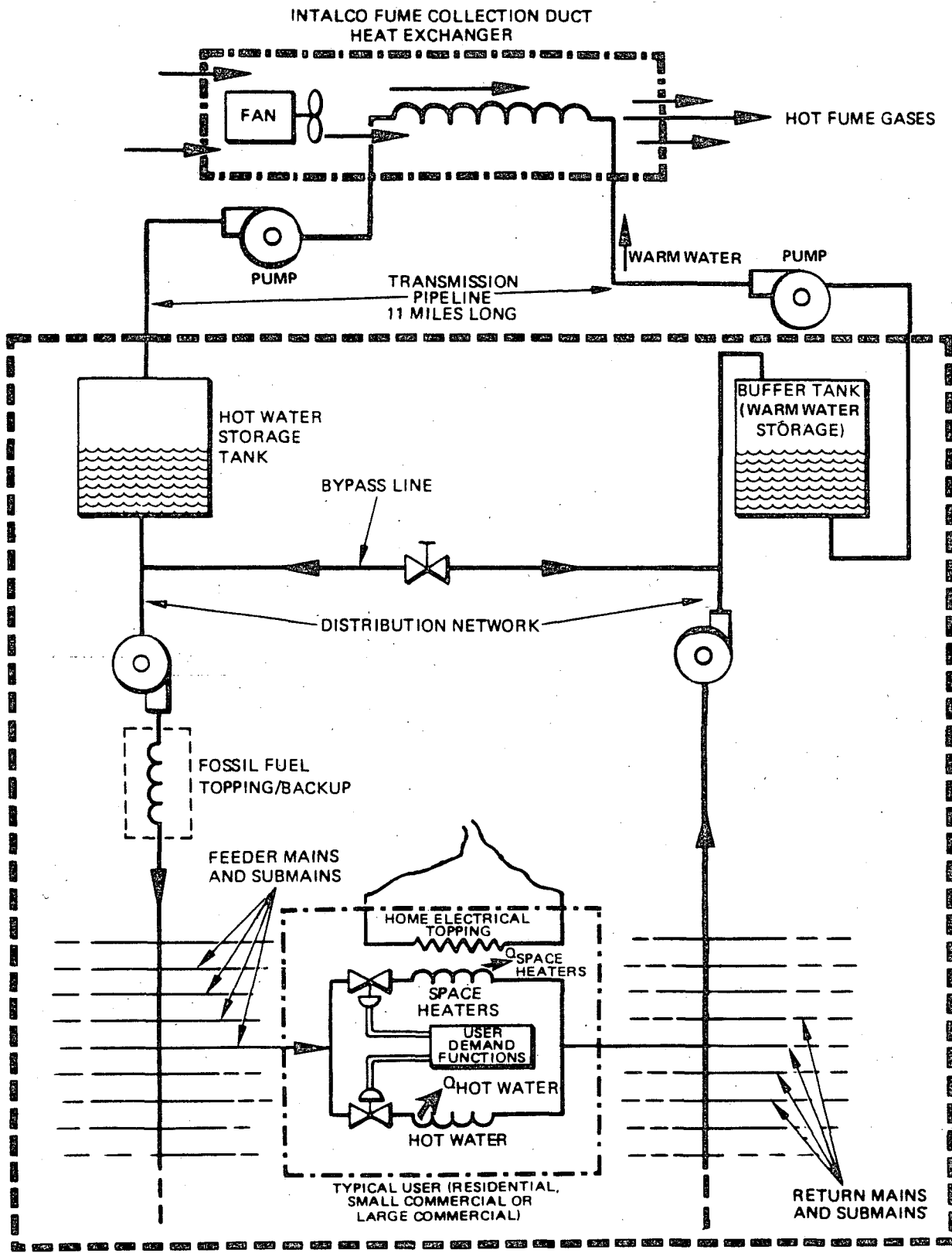




NET DISPLACED ENERGY
OPTIMIZED DISTRICT HEATING SYSTEM CONFIGURATION.



DISTRICT HEATING SYSTEM FLOW SCHEMATIC ELECTRICAL HOME TOPPING



BELLINGHAM

7.0 PRELIMINARY DESIGN AND ECONOMICS – TASK VI

The primary functions of Task VI are use of the results of Task V cost and sizing analyses to develop a preliminary design of the overall district heating system, preliminary designs of any nonstandard major system components, and to perform the preliminary system design economic analyses to determine the economic competitiveness and viability of the proposed system against the cost of utilizing conventional fossil fuels.

7.1 PRELIMINARY DESIGN

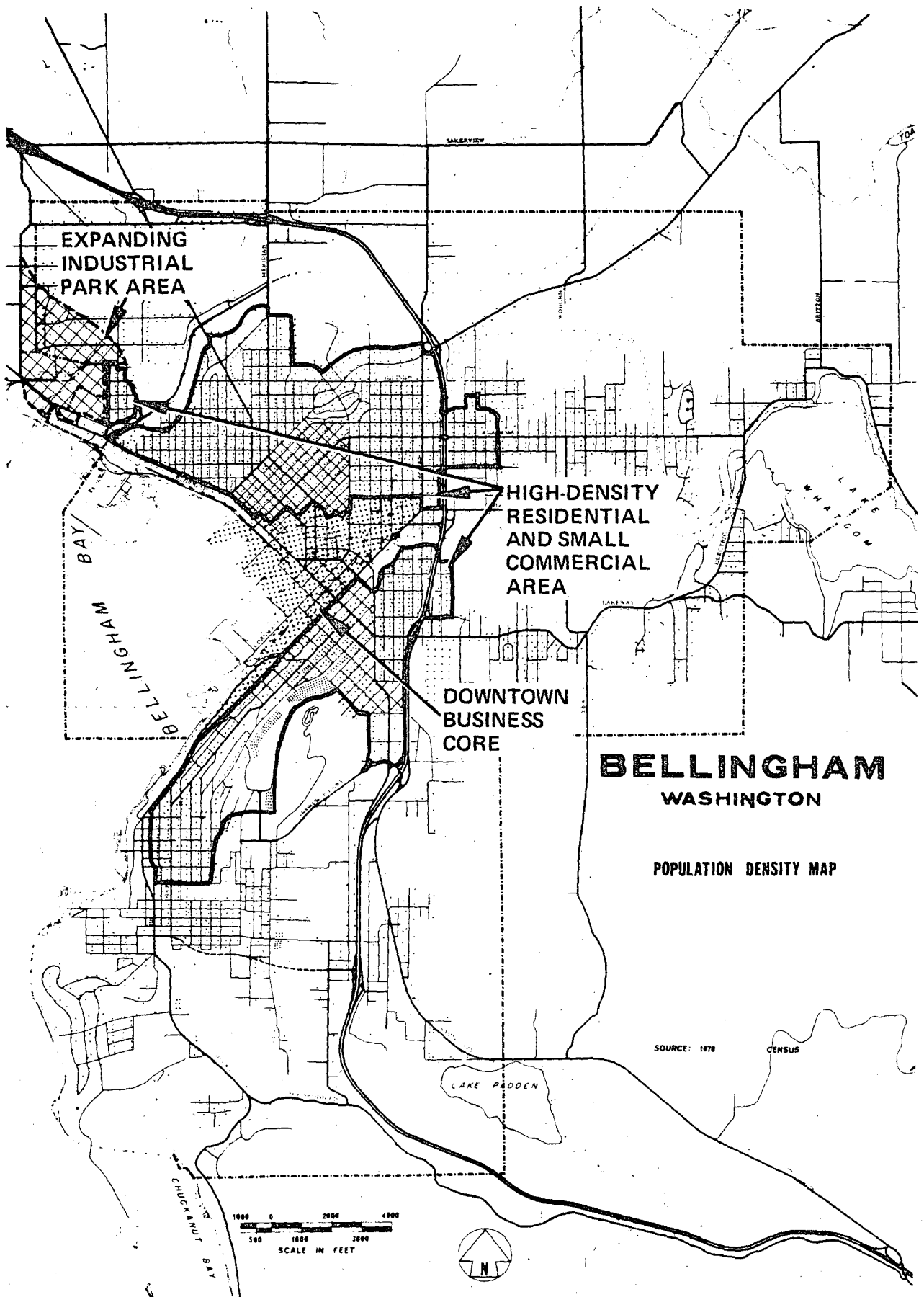
7.1.1 Overall System

The service area of the proposed Intalco/Bellingham district heating system is shown in Figure 38. The district system, as shown, would serve the downtown central business core, the high density residential and small commercial areas of the city, and an expanding industrial park area on the northwest corner of the city. The system would serve approximately 5,520 residential customers, approximately 990 smaller commercial customers, and approximately 17 large commercial customers. Apartment complexes are included in the commercial user categories. This area corresponds to an estimated 1985 user mix of 53% of the Bellingham housing units, and 75% of the commercial users. The average yearly space heating and hot water heating energy requirements that would be supplied by the district heating system is 1.14×10^{12} Btu/year. The design peak energy demand (0°F day) capability of the system is equal to 5.08×10^8 Btu/hr.

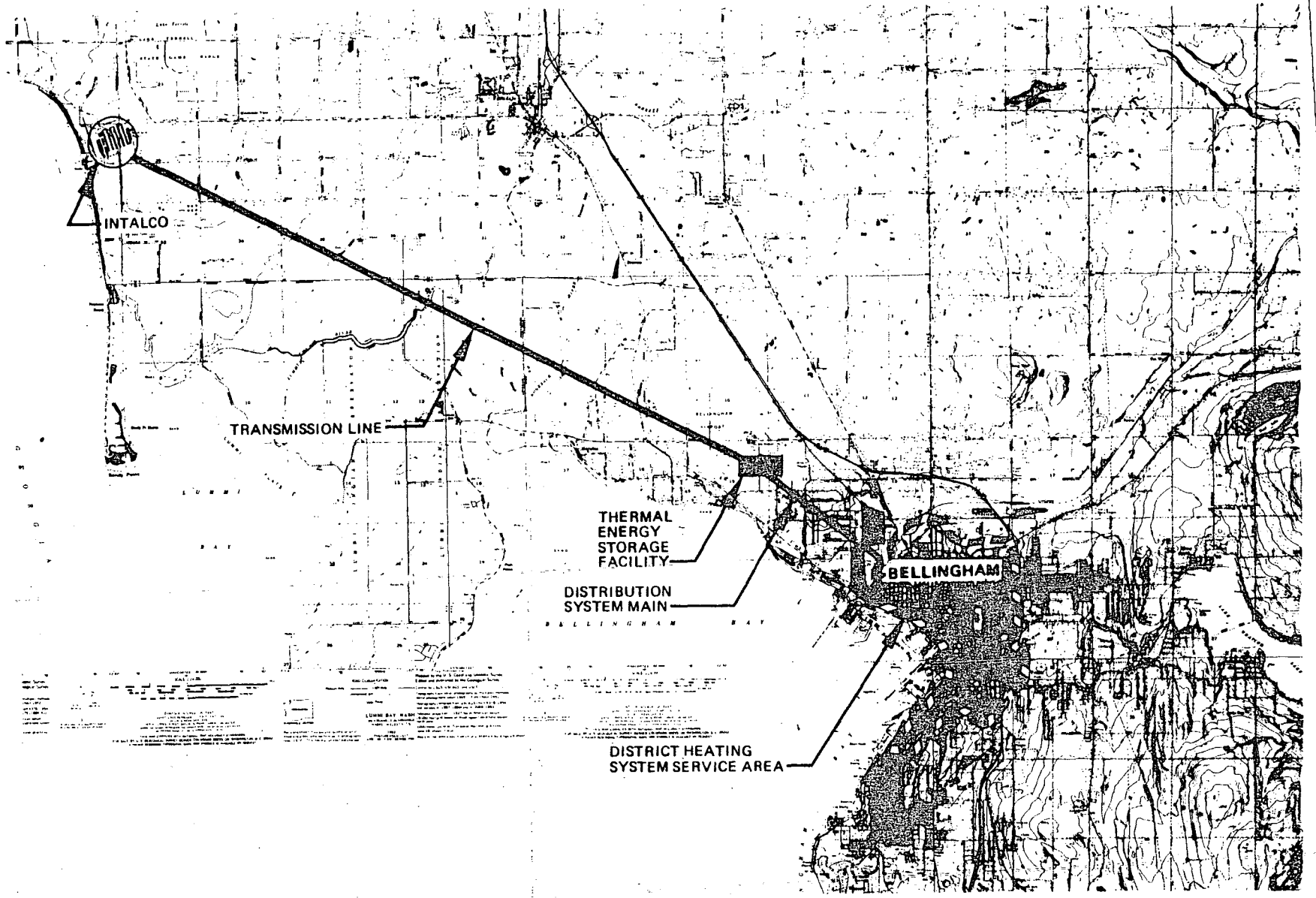
The district heating system could be expanded outside the proposed areas, but the lower density (users/mile²) of the additional users would result in a significant increase in the distribution network cost per added user which would result in higher energy costs to supply those users.

Based upon the Task V analysis, the minimum average energy cost (\$/Btu supplied) district heating system could be achieved by reducing the area supplied by the district heating to approximately 50% of the proposed system size. While reducing the supplied area would result in a loss of over 6.9×10^{11} Btu/year in displaced energy, the cost of the energy supplied to each user would only be decreased by approximately 10%, as in this region the demand density is approximately constant.

The overall layout of the district heating system is shown in Figure 39. The underground transmission line (25-inch diameter polymer-lined concrete, 2 inches of urethane foam insulation, average flow rate 2.86×10^6 lbs/hour or 3.73 ft/sec) from Intalco would run in a straight line (10 miles from Intalco to the thermal energy storage tanks, located on the outskirts of Bellingham). Twenty-four heat recovery heat exchangers would be installed in the fume collection ducts leading to the baghouses. The design of the heat exchangers is discussed in paragraph 7.1.2.



OVERALL BELLINGHAM DISTRICT HEATING SYSTEM LAYOUT



89

Figure 39

The thermal energy storage facility would consist of two insulated tanks, each 10^8 gallons. One tank will be the thermal energy storage tank, and the other tank will act as accumulator (buffer) for when hot water is drawn out of the hot store to meet peak demand periods. The backup/topping boiler and fuel tanks would be located at the same site as the thermal energy storage tanks. The backup/topping boiler capability will be equal to the sum of the maximum total user hourly demand plus any distribution network heat losses, or 3.6×10^8 Btu/hr. The boiler fuel tanks will store sufficient fuel to supply the district heating system for 15 days at maximum capacity. The 15-day period allows the system time to procure additional fuel supplies. The cost of fuel storage tanks and the first fill is included as a first cost item. Replacement of fuel utilized enters as an operating expense.

The site shown in Figure 39 for the thermal energy system is at the Bellingham Airport, which is under the authority of the Port of Bellingham. Discussions with Port personnel have indicated that this is an acceptable location, with the single reservation that the tanks not interfere in any way with the operation of the airport. The convenient ownership and location of the airport site results in its choice over a number of other potential sites in the general area.

The distribution system main would run underground from the thermal energy storage facility into the Bellingham service area along street right-of-ways. Underground feeder mains would branch off from the distribution main and run in the street easement. The various users would be connected off the feeder mains. The return lines would be buried in the same trenches as the feeder and distribution lines. The distribution, feeder and return lines would be polymer lined, concrete pipes with a 2-inch-thick urethane foam insulating layer. The user connection lines may be of either CPVC (chlorinated polyvinyl chloride) pipe or polymer-lined concrete. Either would be insulated with 1 inch of urethane foam insulation, depending upon the size of the connection line. The exact route of the distribution and feeder mains would have to be determined upon the basis of a detailed energy demand survey of the service area. This detailed energy demand survey is beyond the scope of the current program. The user interface with the district heating system will vary, depending upon the existing space heating and water heating equipment currently in service. The connection charges, and the cost of the user retrofit and interface devices, are assumed to be borne by the utility.

The total cost of the proposed district heating system is $\$6.33 \times 10^7$ in 1977 dollars. A detailed cost breakdown of the system showing the cost of the various components is presented in Table 8.

7.1.2 Hardware Design

The major district heating hardware items are the:

1. Thermal energy storage tanks
2. Insulated polymer-lined concrete pipes
3. Pumps

Table 8
DISTRICT HEATING SYSTEM COST BREAKDOWN

CAPITAL COST FACTORS (DOLLARS (1977))			
TRANSMISSION PIPELINE			
PIPE	6.36E+06	PUMPS	4.48E+04
TOTAL	6.4045E+06		
ALUMINUM PLANT HEAT EXCHANGERS			
HEAT EXCHANGER	4.93E+06	FANS	1.41E+05
PUMPS	4.97E+03	PLANT FACTOR	1.5
TOTAL	7.6176E+06		
STORAGE			
TANKS (2EACH)	5.34E+06	INSULATION	1.22E+06
COST FACTOR	1.2		
TOTAL	7.8702E+06		
RACKUP AND TOPPING SYSTEM			
BOILERS	9.83E+05	FUEL TANK	1.97E+05
FUEL	5.53E+05	COST FACTOR	1.2
TOTAL	1.9679E+06		
DISTRIBUTION SYSTEM			
INSTALLED PIPING AND VALVES			
SQUARE MILES	4.07	AT	6.21E+06 DOLLARS/50 MILE
TOTAL	2.5266E+07		
ENGINEERING AND ADMINISTRATION			
TOTAL	5.8951E+06		
TOTAL SYSTEM CAPITAL COST - 5.502133E+07			
USER			
CONNECTION	3.00E+06	RETROFIT	5.24E+06
TOTAL	8.2440E+06		
TOTAL CAPITAL COST 6.326532E+07			

4. Backup/topping boiler
5. User interface devices
6. Aluminum plant waste heat recovery heat exchanger

The thermal storage tanks would be field fabricated, conical top, steel tanks. The tanks would be fabricated to API or equivalent standards. Each tank would be covered with a 6-inch-thick layer of sprayed urethane foam. The foam, in turn, would be covered with a sprayed-on weather-proof coating.

The overall design efforts assume the availability of insulated, polymer-lined, concrete pipe in appropriate sizes at the start of construction.

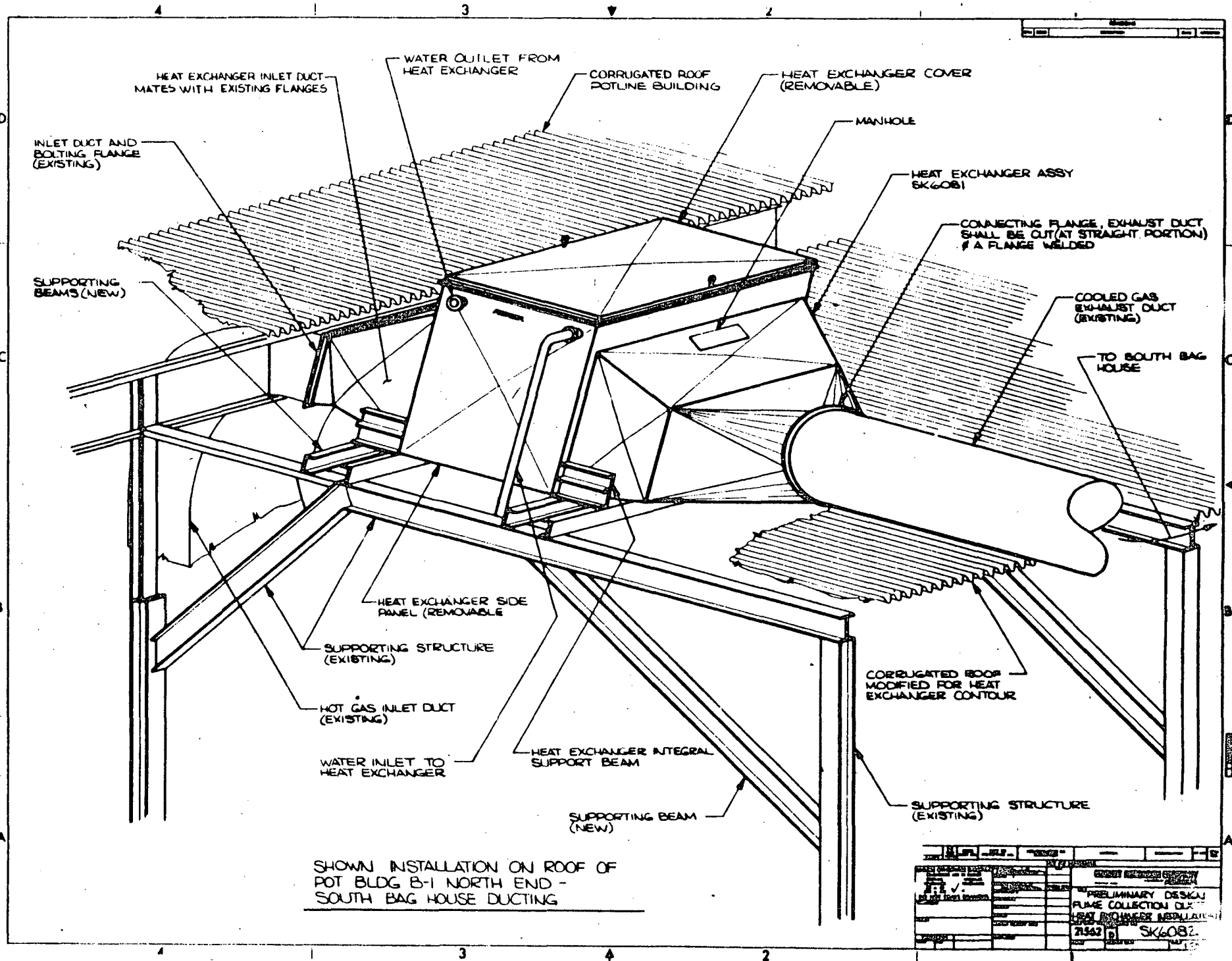
The system pumps for both the transmission lines and the distribution network would be standard, off-the-shelf items, and hence, no specific hardware design is required. The user interface devices (space heating and water heating heat exchangers) would have to be selected and sized, based upon the specifics of each installation. No specific hardware design is required, since the appropriate interface devices can be selected from standard off-the-shelf items.

The backup/topping system would be shop fabricated package "boiler".

The only portion of the district heating system which would not be off-the-shelf hardware and has to be specifically designed for this application are the waste heat recovery heat exchangers. Figure 40 shows a preliminary design drawing of the aluminum plant waste heat recovery heat exchanger. The heat exchanger design was upon the plant/district heating system interface requirements (described in paragraph 5.2) and upon the Task V optimization studies (pressure drop, tube spacing, cross-section flow area, and heat exchanger surface area). The design of the heat exchanger includes a gas side bypass so that maintenance may be performed on the heat exchanger without releasing fumes to the environment. The heat exchanger is shown installed on the potline building roof in Figure 41.

7.2 ECONOMIC ANALYSIS

There is a wide variety of standard economic profitability parameters. The most widely used include return on investment (ROI), present value, net present value (NPV), and rate of return (ROR). The ROI is the expected annual profit divided by the total capital invested. The present value of a proposed system is found by discounting the income for each year of the system economic life to the present, and summing. The net present value (NPV) is the difference — present value less capital cost. The ROR is equivalent to the capital cost interest rate which would produce a NPV of zero for the investment. The ROR is, therefore, an indicator of the profitability of a particular investment or system.



SHOWN INSTALLATION ON ROOF OF
 POT BLDG B-1 NORTH END -
 SOUTH BAG HOUSE DUCTING

PROJECT NO.	DATE	BY	CHECKED
7562			
PRELIMINARY DESIGN			
FUME COLLECTION DUCT			
HEAT EXCHANGER INSTALLATION			
SK6082			

Each of the various economic parameters above is sensitive to the various economic assumptions (such as equipment life, interest rates, cost escalation rates, energy escalation rates, etc.) used to generate the parameters. When comparing alternative investments, realistic comparisons can only be made with common baseline economic assumptions. The economic assumptions described in this section are based upon the pertinent portions of an ERDA/EPRI required revenue methodology document entitled, "The Cost of Energy From Utility-Owned Solar Electric system", ERDA/JPL-1012-76/3. The primary economic assumptions are summarized below:

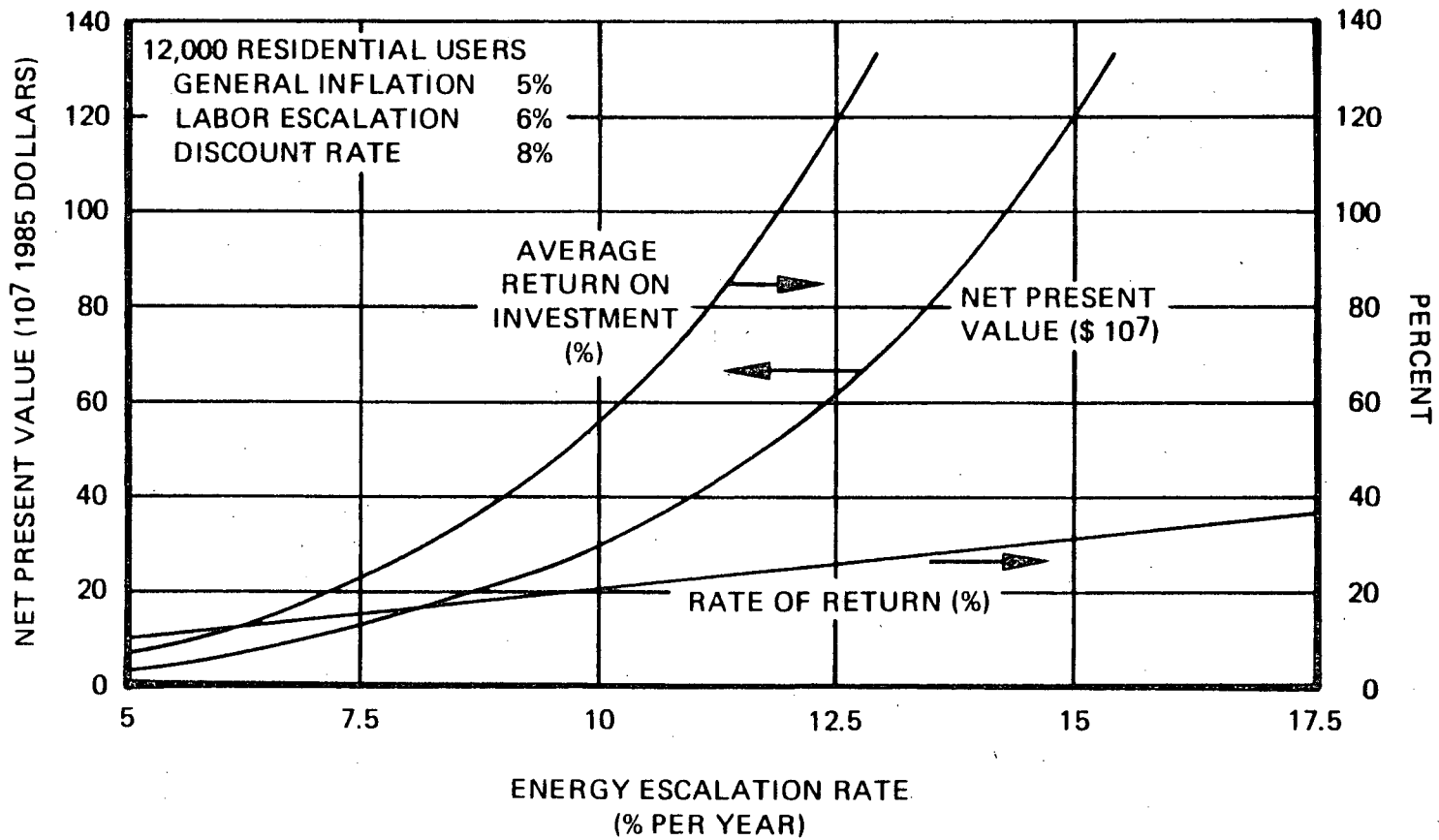
1. Economic system life – 30 years
2. After tax cost of capital (effective interest rate) – 8%/year
3. General inflation rate – 5%/year
4. Labor escalation rate – 6%/year
5. Publicly owned utility
6. Start of system operation – 1985

One of the most influential variables in the entire analysis is the energy escalation rate. Ten percent (inflating dollars) has been used as a baseline figure, following the recommendation of ERDA/JPL-1012-76/3. A sensitivity analysis was performed for the energy escalation rate. The result of this analysis is presented in Figure 42 as the average return on investment, net present value, and rate of return for various energy escalation rates. As shown in Figure 42, the profitability of the overall investment is strongly dependent upon the energy escalation rate. This is expected, since the value of the displaced energy is increasing with the energy escalation rate; while the district heating system expenses escalate at the lower labor and general inflation rates. The system does show profitability for energy escalation rates as low as 7.5% (approximately 2.5% in constant dollars).

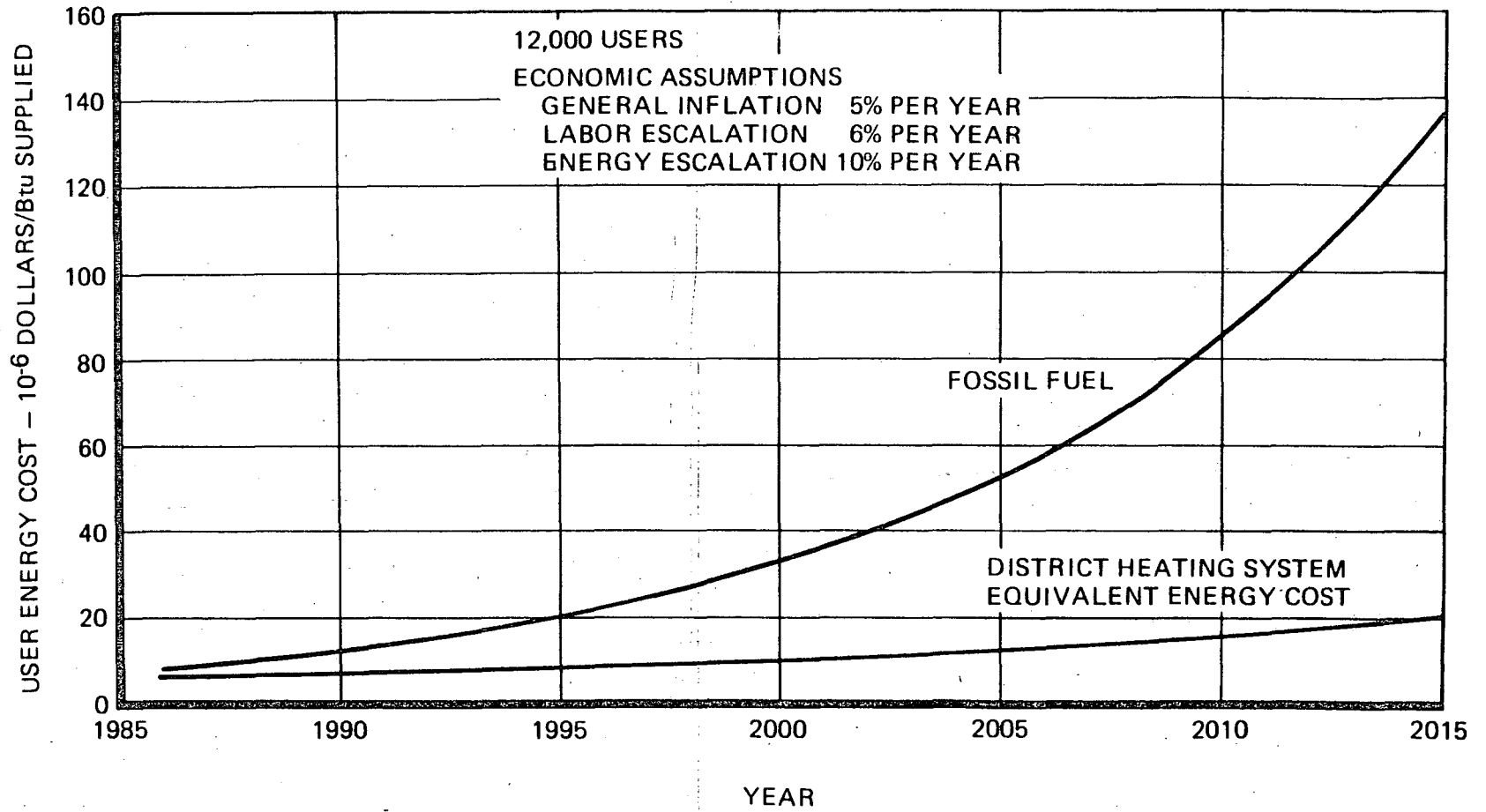
When dealing with alternative energy recovery systems, a convenient and tangible evaluation parameter is the cost of the energy supplied to the user (\$/Btu). For any given year, the cost of the supplied energy is equal to the annual total system cost (including operation, maintenance, principle payments and interest costs) divided by the number of Btu's supplied to the various users. The difference between the cost of fossil fuel energy and cost of supplied energy represent the cost saving in \$/Btu. To put these two costs on the same basis, the energy costs must be based upon the energy usefully consumed, i.e., corrected for the efficiency of the user space and water heaters. Using the 70% space and hot water efficiency consistent with Section 6.0, effectively increases the cost of the fossil fuel energy by a factor of 1.43. Energy supplied by the district heating system is utilized at 100% efficiency, typical of nonvented heaters.

Since the value of energy and the costs of labor, materials, etc., are escalating, the difference between the cost of the user supplied energy and cost of fossil fuel energy will vary with time as shown in Figure 43. One method of examining the cost of energy supplied to the user by the district heating utility over the life of the district heating system is the leveled energy cost. This is a single number representing time average of the energy costs from the standpoint of the utility.

EFFECTS OF ENERGY ESCALATION RATE



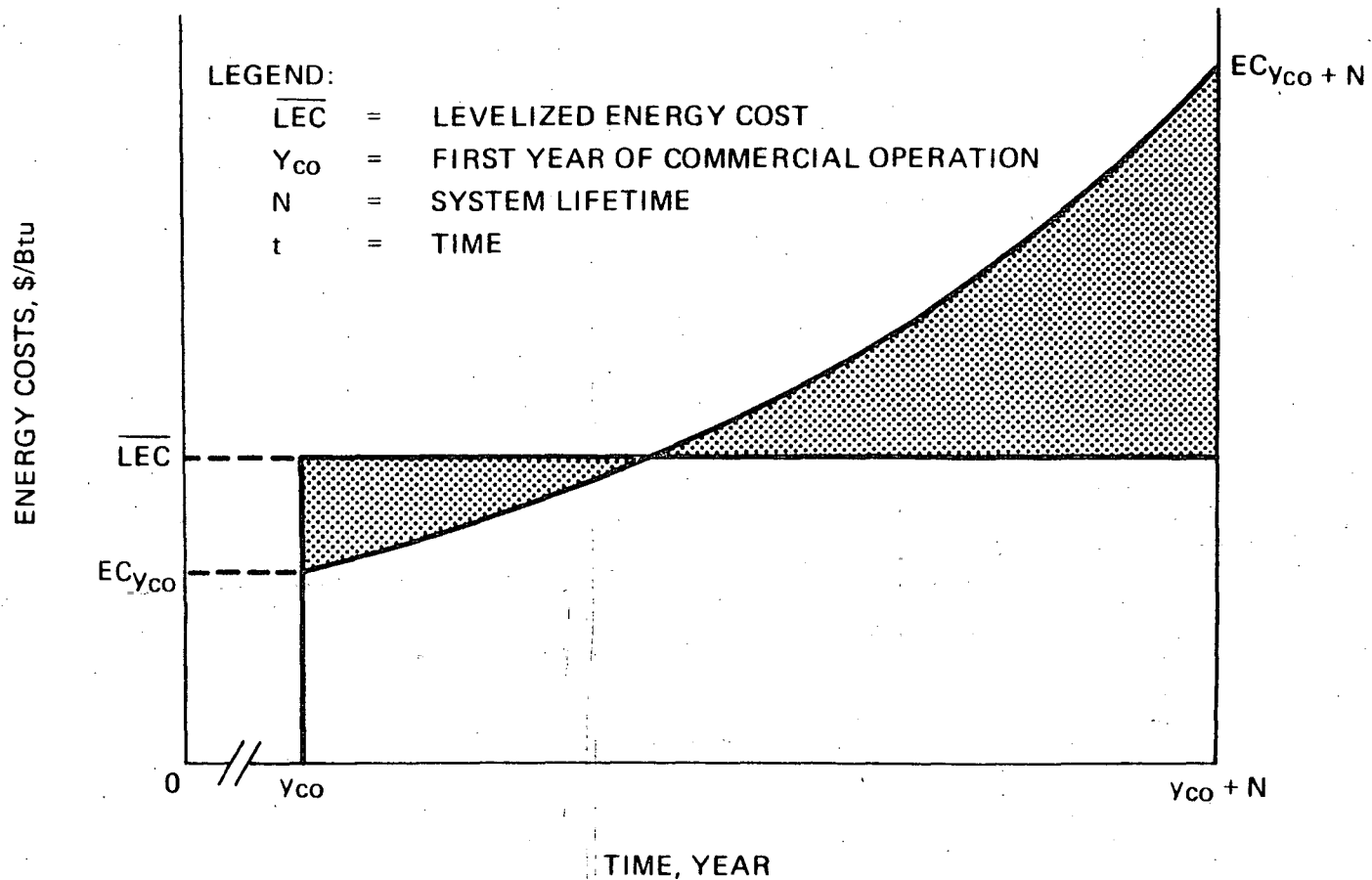
USER ENERGY COST AS A FUNCTION OF TIME



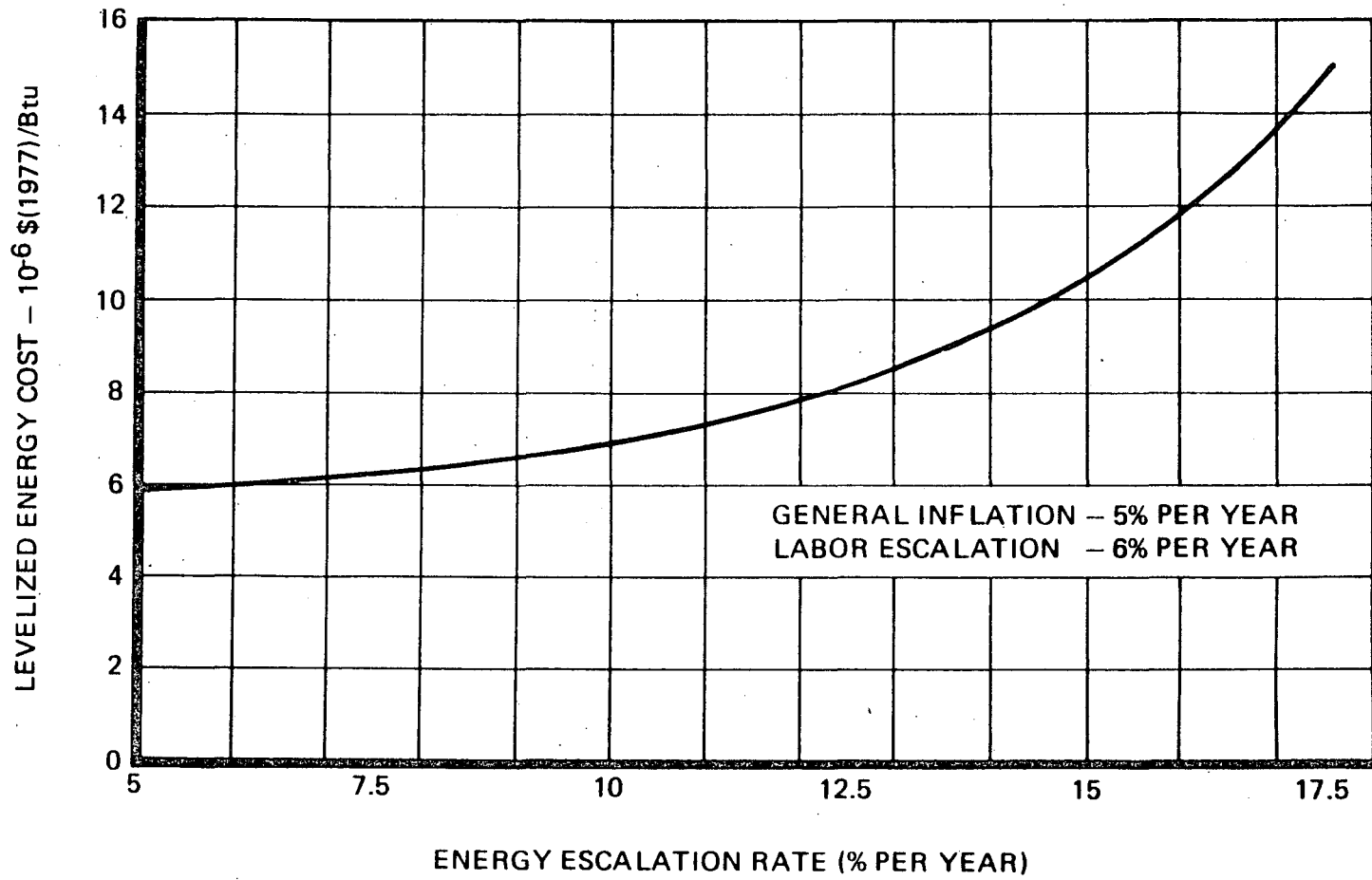
The levelized energy cost (LEC) relationship is illustrated in Figure 44. The horizontal line at LEC represents the effective cost of the particular energy parameter in \$/Btu. The curved line labeled EC represents a hypothetical series of growing energy costs. The LEC is a time average energy cost, in that it represents a uniform distribution which, over the same time interval (start of plant operation to end of economic system life) has the same present value. For this to be true, the two shaded areas must also have equal present values. (The areas shaded are not equal geometrically, reflecting greater discounting of later year revenues.) Thus, the LEC represents an overcharge in early years and an undercharge in later years. In present value terms, however, the two approximations cancel one another, so that the distribution of constant charges has exactly the correct present value. A description of the LEC algorithms is presented in ERDA/JPL-1012-76/3.

The LEC for the district heating utility supplied energy is shown in Figure 45 as a function of the energy escalation rate. As shown, the LEC for the district heating system is very insensitive to the energy escalation rate.

COMPARISON OF LEVELIZED ENERGY COST WITH GROWING ENERGY COST



DISTRICT HEAT SYSTEM LEVELIZED ENERGY COST
12,000 RESIDENTIAL USERS OPTIMIZED SYSTEM CONFIGURATION



2901482

100

Figure 45

8.0 SYSTEM ASSESSMENT AND PHASE II PROGRAM PLAN

The previous sections have presented the results of the first phase of a multi-phase program leading to full-scale test demonstration of a low temperature energy recovery system for the aluminum industry. The nation-wide impact of the technology is estimated at 6.5 million barrels of oil saved per year, based upon the estimates made from the preliminary design for the example site, the Intalco Aluminum plant in Ferndale, Washington. Economic analysis of the system yields very favorable results, making the overall system very attractive for additional evaluation.

The technical assessment of the system performed in this preliminary study has found no fundamental problems to impede implementation of the design approach. However, prior to implementation on a national basis, full-scale demonstration of the technical and economic feasibility of the system is required. A four-phase plan leading to such a demonstration by 1985 is presented in the remainder of this section. Whereas the effort so described could be lumped into a "Phase II program plan", a more definitive plan is evolved by separating the proposed effort into four phases, allowing incremental funding and evaluation of the system as it proceeds to a formal full-scale demonstration. It is recommended that this demonstration be carried out with Intalco Aluminum Corporation and the surrounding communities: Ferndale and Bellingham, Washington. The four program phases are as follows and depicted in Figure 46:

- Phase II — Pilot Plant Detail Design
- Phase III — Fabrication, Assembly and Test of Pilot Plant
- Phase IV — Detail Design of Full-Scale Demonstration System
- Phase V — Fabrication, Assembly, and Test of Demonstration System

The following paragraphs describe each phase in additional detail.

8.1 PHASE II – PILOT PLANT DETAIL DESIGN

The goals of this phase are two-fold:

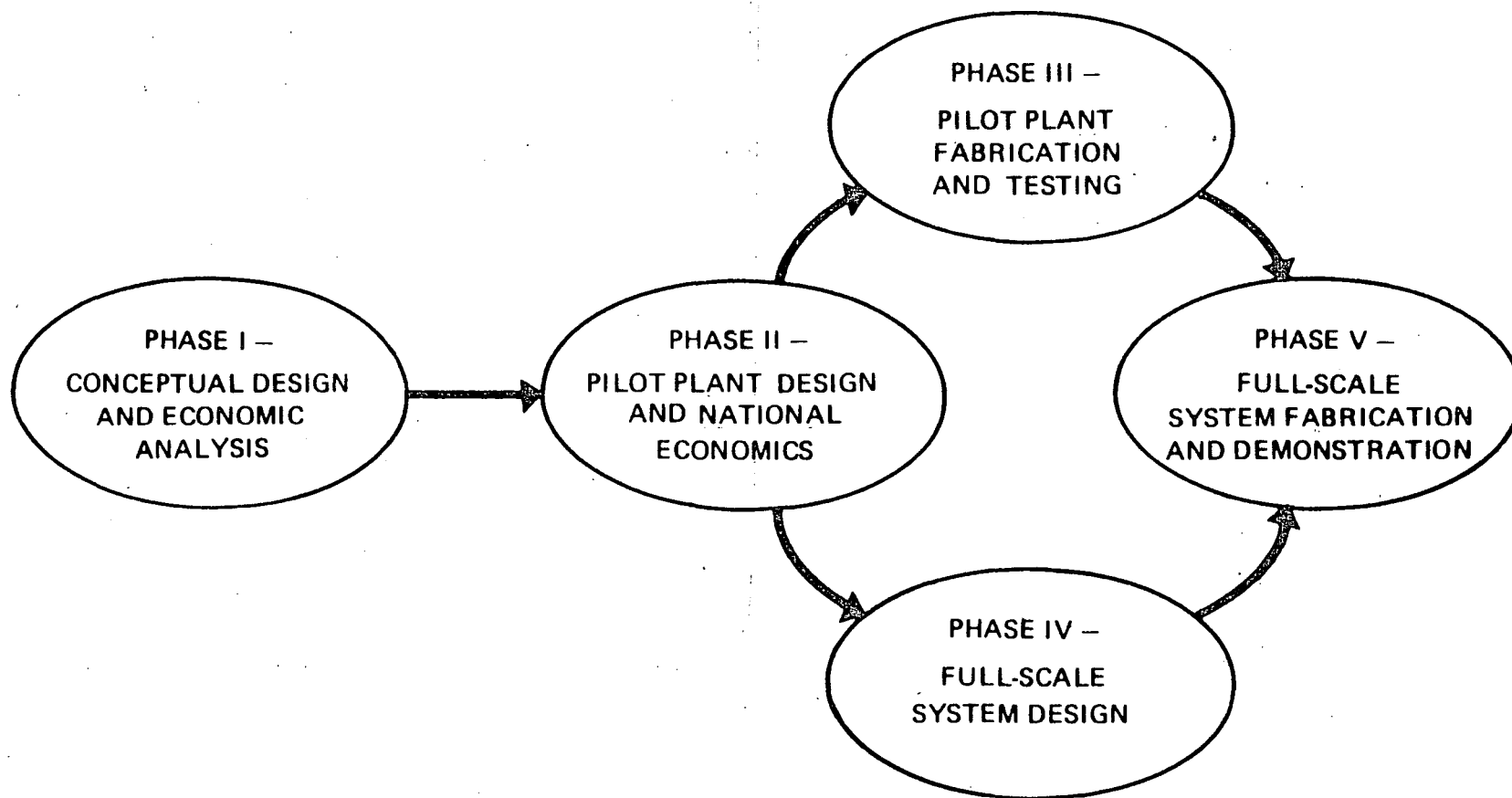
1. Complete a detailed design of a pilot plant system that will demonstrate the technical and economic aspects of the heat recovery and transmission systems.
2. Use pilot plant detailed design to update Phase I conceptual design and evaluate national economic impact.

To achieve these goals and provide adequate program control, the Phase II program will be accomplished in five tasks.

UTILIZATION OF REJECT HEAT FROM ALUMINUM SMELTING

IMPLEMENTATION PLAN FOR DEVELOPMENT/DEMONSTRATION OF HEAT RECOVERY AND DISTRICT HEATING SYSTEMS

- OBJECTIVES (1) CONSTRUCT A FULL-SCALE DEMONSTRATION SYSTEM TO EVALUATE PERFORMANCE AND ECONOMICS
- (2) REMOVE SOCIAL BARRIERS AND IMPEDIMENTS TO INDUSTRIAL WASTE HEAT RECOVERY/DISTRICT HEAT SYSTEM IMPLEMENTATION



8.1.1 Task I – Pilot Plant Requirements

During Task I, a complete study to establish the pilot plant design requirements will be conducted. At present, it is recommended that the heat recovery system be designed to extract heat from 1 of the 24 existing baghouse duct works at Intalco, and size the heat exchanger which will be nominally full scale. This design will capture 4% of a full-scale heat recovery system. The heat exchanger will be sufficiently large enough to cost effectively duplicate all performance parameters of a full-scale system. The baseline application (district heat/hot water to Ferndale) will be reanalyzed to verify that the transmission and user system will provide adequate data for full-scale system sizing. In addition, cyclic demand levels will be fixed and the interface requirements with the aluminum plant will be established.

An interface specification will be prepared to summarize the findings of the above study. Provisions for maintenance will be specified, based upon the aluminum plant operational constraints. The specification will be analyzed to ensure that all code requirements are included.

Also during this task, the location of the transmission piping will be established. A review of county/city drawings will be conducted to define the shortest route allowable for the system.

The storage system capacity will be specified during this task. The daily/seasonal load demands for the using community will be reviewed and an optimal storage size/fossil backup mix will be established.

8.1.2 Task II – Component Design

After establishing the interface and performance requirements of the pilot plant system in Task I, the detailed design of the pilot plant system will be initiated. The two major components that comprise this system, the plant heat exchanger and the transmission system, will be analyzed and designed in detail. For simulation and economic modeling, a heat exchanger design that represents a user system will also be prepared.

Plant Heat Exchanger Subsystem Design – Detailed design drawings of the pilot plant heat exchanger will be prepared. All necessary materials, manufacturing processes, and code requirements will be specified. A structural analysis will be conducted to ensure that the effects of pump-induced vibration and thermal stresses will not alter system life expectancy.

Transmission Subsystem – The transmission system includes all piping, fittings, valves, pumps, etc., necessary to connect the plant heat exchanger to user heat exchangers. Utilizing the design requirements established in Task I, the transmission system layout will be completed. Thermal performance analysis will be conducted to determine heat loss versus insulation thickness for the network. Parametric studies of piping size, fluid flow rates and insulation will also be conducted. Detailed working drawings of the transmission system will

be prepared and a preliminary construction specification will be completed. This information will be used to prepare Phase III system costs. The development status review of PLPC pipe will be updated to verify projected availability dates.

User Heat Exchanger Subsystem – Two heat exchangers representative of residential and commercial end-use heat exchangers will be designed. A survey of the pilot plant end user will be performed to determine geometric and operational constraints. Baseload and peak load levels for each application will be established and an optimal mix of district heat/fossil fired backup energy will be established. The user heat exchangers will then be designed to satisfy the operational requirements of minimum capital costs. Retrofit costs will also be determined.

Storage System – The baseline storage system from Phase I is a large tank of hot water. The optimal size of a full-scale system will vary by locality and backup energy costs. To make the storage system universal to all possible locations, it is recommended that selection be made of a mid-range storage condition for pilot plant sizing. Tradeoff studies will then be performed on maximum recovery temperature, insulation thickness, and storage duration.

Location of the storage subsystem will be further analyzed. During Phase I, a storage facility location near the user appeared optional. Further refinement of the storage subsystem will include matching of individual commercial and/or residential demand to availability. During this subtask, the storage tank and components of the pilot plant will be designed in detail, and existing components will be utilized where appropriate.

Since the decision to emphasize proven technology yielded the choice of steel tank storage, both the cost and the feasibility of aquifer storage have become better defined. Estimates for the efficiency of aquifer storage are now in the range of 85 to 90 percent, a very attractive figure indeed. During Task II, the effect of the maturation of aquifer technology upon the overall system will be assessed. Note that the proposed pilot plant, at 1/24 scale, still requires a storage of 4 million gallons, definitely in the size range where aquifer energy storage is becoming competitive.

Controls and Instrumentation – Several sets of controls are required in the system to maintain system optimization, reliability, and prevent operational problems to the utility. During this phase of the total aluminum waste heat demonstration program, those controls necessary to assure proper pilot plant operation will be incorporated and optimization of the controls will be conducted on the full-scale system demonstration.

Pilot plant instrumentation will be established based upon performance requirements. Since the prime purpose of a pilot plant is to determine if predicted performance is achieved, the design effort will specify type and location of instrumentation to assure adequate data recovery for system analysis.

8.1.3 Task III – Review of Full-Scale System Design and Economics

During this task, the Phase I conceptual design will be reviewed and changes incorporated based upon the detailed plant design. Changes to operational constraints will be made where appropriate. Cost modification to the system will be incorporated based upon current state-of-the-art technology. It is the intent of this task to reanalyze the economic studies conducted during Phase I and determine if full-scale system economics remain favorable with projected displaced energy costs.

8.1.4 Task IV – National Economic Impact Analysis

Upon completion of the Task III cost update, a cost study will be conducted on utilizing this waste heat recovery/application system for the United States aluminum smelting plants. Cost studies will be similar to the Phase I cost study effort. Systems will be sized by plant capacity and user demand loads which will be based upon historic degree-day requirements and national energy use profile for the specified area. The information retrieved during the Phase I surveys will be used to conduct a system cost study for selected plants. Information to be determined during this phase includes the following for the various locations:

1. Transmission subsystem
2. Geographic layout
3. System capital cost per plant
4. Energy displaced per plant
5. Projected payback periods
6. Energy demand density
7. Presence of known aquifer

It is anticipated that a large number of aluminum plants will have more attractive energy displacement economics than the baseline Intalco/Bellingham system due to higher temperatures and/or closer geographic distances from plant to population centers. Since the baseline concept appears to be "middle-of-the-road", the basic technical/economic results will be adaptable to all plants within the United States.

8.1.5 Task V – Program Plan for Fabrication, Assembly, and Test of Pilot Plant

During this task, the program plan to construct and test the Phase II pilot plant will be established. Detailed cost and schedule information will be prepared and the team members to implement this phase will be selected. A work statement will be prepared and submitted.

8.2 PHASE III – FABRICATION, ASSEMBLY, AND TEST OF PILOT PLANT

During this phase, fabrication and testing of the pilot plant design in Phase II will be implemented. It is anticipated that this phase will be divided into four tasks representing the major subsystems of the pilot plant.

8.2.1 Task I – Fabrication, Assembly and Test of Plant Heat Exchanger

The heat exchanger designed in Phase II will be fabricated per design specifications. Performance testing will be conducted in a test rig that simulates air flow from the

aluminum pot lines. Use of a test rig will allow for close controls of the gas properties in order to assess the performance of the heat exchanger during nominal and off-nominal operational conditions.

After achieving satisfactory operation and performance of the heat exchanger in the test rig, the unit will be installed in the selected location in the Intalco Aluminum Corporation plant.

8.2.2 Task II – Fabrication, Assembly and Test of Transmission System

Following completion of Task I, the transmission system will be investigated. A representative length will be installed in a test rig to measure heat losses and fluid flow pressure drops under various operational conditions. Upon successful completion of performance test verification, the piping will be installed from the aluminum plant to the user. Performance testing of the in-place piping system will include tradeoff studies of pump power requirements and entrance level temperatures. Sufficient data will be obtained to quantify transmission system performance under nominal and off-nominal operational limits.

8.2.3 Task III – Fabrication, Assembly and Test of Storage Plant

In parallel to the Task II effort, the selected storage system will be fabricated and tested. The unit will be built at the designated location and charge/discharge testing will be conducted with controlled input water temperatures. Upon completion of the transmission system, the storage subsystem will be connected and tested in conjunction with the transmission system.

8.2.4 Task IV – Fabrication, Assembly and Test of User Heat Exchanger

In parallel to Tasks II and III, heat exchangers representing nominal conditions in residences and commercial buildings will be fabricated and tested. After achieving satisfactory performance, user heat exchangers for space heating and hot water will be fabricated and installed in the facilities selected in Phase II.

8.2.5 Task V – Pilot Plant Operation

Final assembly of the pilot plant will be completed. Controls will be installed per pilot plant design requirements and system performance will be monitored. Test data will be reduced to verify predicted performance parameters for nominal and off-nominal conditions.

8.3 PHASE IV – FULL-SCALE SYSTEM DESIGN

This phase will be initiated in parallel with Task V of Phase II. Pilot plant operational data will be utilized to optimize the design of a full-scale demonstration system from the Intalco Aluminum plant to Bellingham, Washington. The final product from this phase will be the detailed drawings and specification of the full waste heat utilization system.

8.4 PHASE V – FABRICATION, ASSEMBLY, AND TEST OF DEMONSTRATION SYSTEM

This phase will entail construction and performance monitoring of the full-scale demonstration system. Data will be gathered to assess total system cost, component size/performance sensitivity on total system cost, and economic payback. Component design information will be of sufficient detail to implement system construction of other economically attractive locations.

9.0 SUMMARY AND CONCLUSIONS

The first phase of a five-phase program has shown that waste heat recovery from aluminum smelting operations is technically feasible and economically viable. A ready demand for this energy exists for comfort conditioning for human habitation. Energy stored in the form of hot water improves the utilization of the continuously available source by the strongly time variant demand.

A specific aluminum plant site has been analyzed during the study, resulting in a preliminary design from which the system performance may be estimated. This specific site, the Intalco Aluminum plant coupled to the cities of Bellingham and Ferndale, shows the prospect for displacing 1.37×10^{12} Btu's/year of fossil fuel energy (assumed heating efficiency of 70%). Thus, the fossil fuel displaced is 49.4% of the total energy contained above 70°F (2.77×10^{12} Btu/year) in the Intalco fume flow. The specific site analyzed is a reasonably typical aluminum plant, allowing an estimate of the national fossil fuel savings from the example savings fraction at 35.5×10^{12} Btu's/year. These are equivalent to 0.251×10^6 barrels of oil/year (one site) and 6.5×10^6 barrels of oil/year (national).

The system analyzed during the program provides the space heating and hot water heating requirements for a mix of large commercial, small commercial, and single family residential users equivalent to 12,000 single family residences. A storage tank of 10^8 gallons results as the most cost competitive storage volume for above-ground, insulated, nonpressurized steel tanks. It is expected that the maturation of aquifer thermal storage technology will result in less expense associated with storage of heated water which will result in higher energy savings and lower costs, resulting in even better economic parameters.

The system, as designed, incorporates mainly existing proven technology. The only item which presents a potential technology gap is the use of polymer lined prestressed concrete pipe in the required diameter. However, such development is currently in process in Europe, and discussions indicate the development is proceeding rapidly. The maturation of polymer lined prestressed pipe technology appears to be totally feasible by 1985. It is thus estimated that the system could be implemented and proven by 1985.

The system studied shows a cost (1977 dollars) of 63.2 million. Escalating this cost to the assumed 1985 system start yields 93.3 million dollars (1985). At that time, the system "present value" (1985 dollars) is 349.3 million dollars, yielding a system net present value of 1985 of 256 million dollars (1985). Other economic indicators are as follows:

- a. Internal rate of return - 20.8%
- b. Return on investment - 86%
- c. System lifetime (assumed) - 30 years
- d. Averaged energy cost/averaged cost of replaced fossil fuel - 0.255

While there are no technological breakthroughs required before the system can be implemented, the overall system will need a full-scale demonstration before a widespread investment of private capital will be forthcoming. A plan leading to such a demonstration has been formulated. This plan proceeds in four more phases:

- Phase II – Pilot Plant Detail Design
- Phase III – Pilot Plant Fabrication and Testing
- Phase IV – Full-Scale System Design
- Phase V – Full-Scale Fabrication and Demonstration

Rocket Research Company believes that these phases may be accomplished in time to allow the start of a national implementation program by 1985.

APPENDIX A

YORK CENTER
REDMOND, WASHINGTON 98052
(206) 885-5000 TWX 910-449-2861

ROCKET RESEARCH COMPANY
A DIVISION OF **ROGACOR**

The Rocket Research Company (RRC), is currently under contract to the Energy Research and Development Administration (ERDA) to investigate the utilization of waste heat produced during the smelting of aluminum. We are being assisted in this study by the Bonneville Power Administration (Branch of Power Resources) and the Intalco Aluminum Corporation. While other waste heat sources and applications are being considered, the primary energy source being investigated during this program is the gas stream from the aluminum reduction pots enroute to the bag houses. The primary application for this energy being studied is residential and commercial space and water heating, i.e., a district heating system for the surrounding communities. District space and water heating has been widely used in Europe for many years; for example, in 1975, approximately 42 percent of Denmark's space heating requirements were supplied by district heating sources. In Reykjavik, Iceland (population 90,000), over 99 percent of the space and water heating is supplied from district heating sources (geothermal). In the United States, district heating is primarily used for large urban commercial applications. European district heating systems have shown that it is economically feasible to supply district heating systems from heat sources over 25 miles away. A preliminary analysis of this concept based upon the Intalco Aluminum Corporation's plant in Ferndale, Washington, suggests that homes of over 25,000 people could be economically heated from this one waste heat source.

The purpose of this letter and the attached questionnaire is to gather sufficient information to allow RRC and ERDA to evaluate the feasibility and economics of this concept on a national basis. If any of the information that you supply in filling out the questionnaire is considered proprietary, it should be noted as such on the questionnaire. Any information marked proprietary will be kept confidential by RRC. In return for your assistance with this survey, RRC will send you a copy of the final report at the conclusion of this study.

If you have any other comments or questions, please feel free to contact either me or the Project Manager, L. B. Katter, at (206) 885-5000.

Sincerely yours,

ROCKET RESEARCH COMPANY



Randel L. Hoskins
Principal Investigator

RLH/is
Attachment

ALUMINUM SMELTER WASTE HEAT SURVEY

I. General Plant and Location Information

A. Plant location relative to population centers

1. Please list any towns within a 25-mile radius of the plant and include approximate distance from plant.

<u>Towns</u>	<u>Population Greater Than</u>	<u>Distance from Plant</u>
_____	a. 1,000	_____
_____	b. 5,000	_____
_____	c. 10,000	_____
_____	d. 20,000	_____
_____	e. 50,000	_____

2. Alternately, please return questionnaire with a local map showing the approximate location of the plant relative to the surrounding communities.

B. Rated Plant Capacity _____ Tons/Year

C. Start of Plant Operation _____

D. Production

1974 _____ Tons/Year 1975 _____ Tons/Year 1976 _____ Tons/Year

E. Announced Future Plant Expansion

Increase in capacity _____ tons/year by _____

II. Process Information

A. Type and Number of Reduction Cells

1. Prebake*

a. Side worked _____ b. Center worked _____

2. Soderberg*

a. VSS _____ b. HSS _____

*In installation where multiple types of cells are used within plant, please note approximate percentage of plant aluminum production produced in each type of cell.

B. Plant Energy Consumption

1. Electrical Consumption (pot electrical power only)

1974, _____ GW-hr 1975 _____ GW-hr 1976 _____ GW-hr

2. Fossil Fuel Consumption

a. Cast House

1976, Natural Gas _____ Mcf/years 1976, Oil _____ gallons/year 1976, Other _____

b. Anode Baking Ovens**

1976, Natural Gas _____ Mcf/years 1976, Oil _____ gallons/year 1976, Other _____

c. Coke and Pitch Requirements

1976, _____ tons/year

**Where applicable

