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U.S. Department of Energy
Assistant Secretary, Conservation
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Office of Renewable Technology
Washington, D.C. 20585
Under Contract No. DE-AC01-76CS20167

March 1982

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MOBILIZABLE RDF/d-RDF BURNING PROGRAM

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MOBILIZABLE RDF/d-RDF BURNING PROGRAM

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Washington, D.C.
Under Contract No. DE-AC01-76CS20167

United States Department of Energy

FOREWORD

This report was prepared for the U.S. Department of Energy (DOE) under contract no. AC01-76CS20167, Task 9. The DOE Project Officer for this task was Chauncey Gould.

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ABSTRACT

The Mobilizable RDF/d-RDF Burning Program was conceived to promote the utilization of refuse-derived fuels (RDF) as a supplement to existing fossil fuel sources in industrial-sized boilers. The program explores the design, development, and eventual construction of a transportable municipal solid waste processing system to produce quantities of RDF or densified-RDF (d-RDF) for use in boiler combustion testing as a supplement to stoker coal or wood wastes. The equipment would be mounted on trailers and assembled and operated at preselected sites throughout the country where approximately 750 tons of RDF would be produced and test burned in a local boiler. The equipment, to include a transportable RDF boiler metering and feed system, would then be moved and operated at two to three test sites annually.

The program is intended to encourage the construction of permanent resource recovery facilities by involving local waste handling groups in operating the equipment and producing fuel, and potential local fuel users in testing the fuel in their boilers.

The Mobilizable Program was developed from two separate tasks (4 and 9) under Contract AC01-76CS20167. The first task developed the concept behind the program and defined its operational and organizational structure. The second task, a follow-up to the first, was intended principally to finalize test locations, develop equipment designs and specifications, and formalize a management program. This report summarizes the principal findings of both Tasks 4 and 9. It identifies the criteria used to identify test locations, outlines the program's management structure, presents design and performance specifications for both the fuel production equipment and boiler fuel feed systems, and provides a detailed evaluation of the parameters involved in burning RDF in industrial-sized boilers. Final conclusions and recommendations identify problem areas encountered in the program, and discuss possible future directions for such a program.

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INTRODUCTION

Program Concept

The Mobilizable RDF/d-RDF Burning Program is intended to promote the utilization of municipal solid waste as an alternative fuel source in selected industrial-sized boiler systems. The program provides for the design and construction of a transportable municipal solid waste (MSW) processing system to produce refuse-derived fuel (RDF) and densified refuse-derived fuel (d-RDF) to be utilized as a supplemental fuel in combustion tests in existing industrial- and institution-sized solid fuel boilers. The equipment, to be mounted on trailers, would be transported to and assembled at preselected sites (probably a landfill site or transfer station) where 600 to 900 tons of RDF or d-RDF would be produced and test-fired in a local boiler. Upon completion of fuel production, the equipment would be disassembled and transported to the next test location.

A major intent of the Mobilizable Program is to serve a catalyst function. The approach allows potential commercial producers of fuel an opportunity to handle local waste, observe and operate equipment, and evaluate processes for future consideration. Potential users of the fuel can benefit from observations of handling, storage, and feed characteristics, and evaluate combustion properties and their effect on boiler performance and operation, all with a fuel representative in quality to that expected from a local commercial facility. As a result of successful testing and the experience gained by the producer and user groups in handling the equipment and fuels, it is intended that both groups will initiate discussions for a follow-on agreement resulting in a permanent, commercial facility.

Background

The Mobilizable Program was developed over two separate tasks sponsored by the Department of Energy (DOE), the results of which are combined here in final report form.

Phase I, the Initiation and Concept Development, introduced the program, outlined its intent and purpose, defined some of the organizational parameters, developed preliminary equipment specifications and system designs, and provided economic analyses of the program itself and of follow-on commercial facilities.

The operating concept that was developed specified agents who would participate in the program and be contractually responsible to DOE for a variety of services. The Program Coordinator would serve as DOE's primary representative and would generally oversee the entire program and coordinate the activities of other agents. The System Equipment Contractor would procure, assemble, and start up the mobile equipment and provide field support at the production sites. At each site, the Production Agent would operate the equipment and produce specified quantities of fuel for testing by the Burn Agent. The Burn Agent (boiler owner or operator) would perform the actual testing and monitor the operation of the unit while assisting in boiler performance and emissions sampling and testing. The Test Agent would be responsible for providing RDF and stack emissions sampling and would assist the Burn Agent in boiler testing. Upon completion of testing at a particular site, the Transportation Agent would move the equipment to the next test location.

As part of the Phase I activities, a list of potential Production and Burn Agents was developed. These groups were contacted to gauge their interest in the program, after which the list was reduced to perhaps a dozen firm candidate sites. The potential agents were presented with Draft Agreements, which defined the scope of the program and their responsibilities should they elect to participate. A test program was developed for activities at both production site and test sites and were presented to each potential agent.

Sufficient interest was shown on the part of potential Production and Burn Agents, and the technical feasibility of the mobile production system was high enough to warrant additional program development as specified in Phase II.

The Phase II research involved three areas of concentration: (1) continuing to discuss and negotiate with potential Production and Burn Agents for their participation in the program and secure signed Agreements to Participate at three to five sites; (2) developing the operational and project management structure necessary to coordinate individual agent activities, provide project monitoring and test reporting, and ensure smooth transition between various program phases; and (3) developing system and equipment design and performance parameters for the mobilizable processing system and related auxiliary equipment. In addition to process equipment, design parameters for equipment to meter and feed fuel into the test boilers were also included.

Intent of the Report

This report contains the results of the concept development and program refinement from both phases. It is intended to provide a basis for any future evaluations concerning the identification of test sites, equipment procurement and assembly, and considerations regarding the viability of the mobilizable concept itself.

Report Format

The report is divided into five principal sections as follows: (1) past and future site-selection evaluation; (2) proposed program management structure; (3) mobilizable system configurations and equipment design specifications; (4) RDF combustion parameters and boiler evaluations; and (5) conclusions and recommendations.

SECTION 2

SITE SELECTION

Introduction

During the initial concept and development phases of this program, a set of criteria was generated and an approach formulated to assist in identifying potential test locations and to gauge the interest of potential Production and Burn Agents in participating in the Mobilizable Program. Approximately 50 production/user groups were contacted, of which 10 to 15 showed strong interest. The efforts focused on boiler owners as the ultimate fuel users whose particular needs relating to fuel costs, quality, and compatibility were critical to the success of the program. In areas where there was interest by boiler operators, the program was presented and discussed with local waste management representatives. As provided for in the second phase of the program, an attempt was made to finalize Agreements to Participate in the program with Production and Burn Agents at three to five individual sites. The approach to and consequent results of those efforts are detailed in this section.

Site-Selection Criteria

The criteria on which potential test sites were identified and evaluated centered on three primary areas:

(1) technical criteria;
(2) economic criteria; and
(3) commercialization potential.

Technical Criteria. 1) Boiler Evaluation--Of particular importance was the need to identify potential test boilers in a certain size range and design that would be compatible with the types of refuse fuels to be produced by the mobile MSW processing system. Based both on characteristic sizes of industrial-type boilers and on limitations related to the fuel production capacity of the mobile system, it was determined that industrial-sized boilers in the range of 75,000 to 150,000 pounds per hour steam flow would be considered. Units in this range have capacities that would permit tests of reasonable duration necessary to gain operating experience and provide representative test data. The quantities of RDF required for testing such units at typical blend ratios (10 to 30 percent RDF) would also match the RDF production rate of the mobile system, while not requiring excessive fuel storage space. Figure 1 illustrates the quantities of RDF required to conduct combustion tests of varying duration and at varying percentages of RDF by total heat input in a representative 100,000 lb/hr boiler.

It was also necessary to identify boilers with existing systems or retrofit capability for handling, storing, feeding, and firing RDF. Only units burning stoker coal or wood wastes as their primary fuel source were considered. These boilers, designed to handle solid fuels, are generally equipped with sufficient fuel storage capacity, spreader-stoker fuel distribution and combustion systems, and ash handling systems suited for RDF burning. Other boiler design parameters critical to the successful burning of RDF are detailed in Section 5, "RDF Combustion Evaluation." Units requiring extensive modifications to successfully fire RDF were considered to be less desirable due to the high cost of such modifications relative to total program costs.

2) Waste Availability--Sufficient quantities of municipal waste must be available locally to insure adequate quantities of RDF for the test burns, and to provide a sufficient flow of waste for any potential follow-on commercial facility.

Economic Criteria. 1) Fuel Costs--For potential Burn Agents to commit to participation in the Mobilizable Program and to a possible long-term contract for the purchase of RDF, it is necessary that certain economic incentives be available in the form of lower

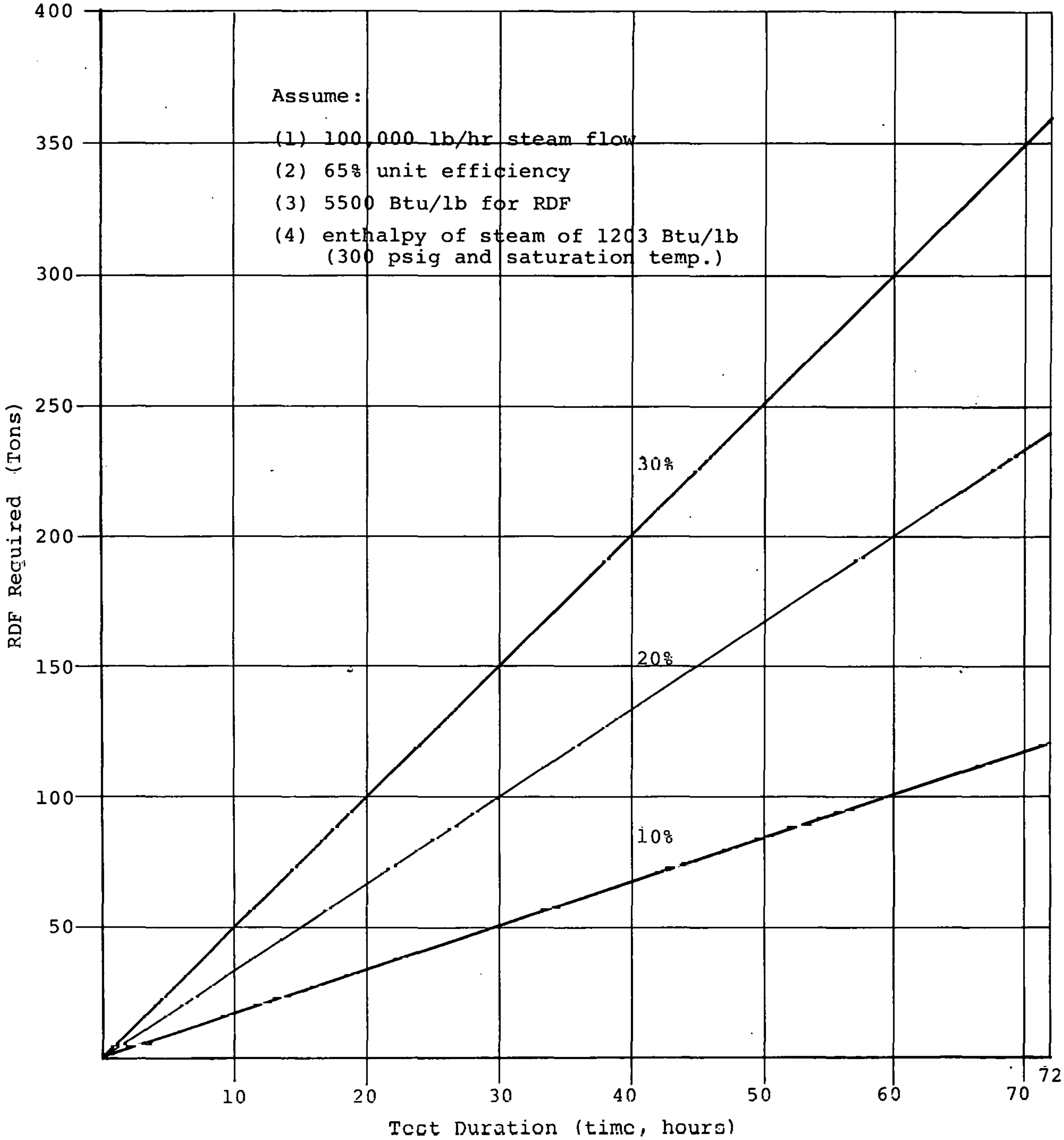

Figure 1. RDF Test Quantities Required for 100,000 lb/hr Boiler

fuel costs. Issues of fuel quality (ash, sulfur content) and availability would enter into any cost calculations. Fossil fuel costs vary with the fuel type (coal, wood), quality, size of purchases, and transportation costs. Determining the value of RDF to a potential user would typically involve an equivalent cost based on energy value of the fuel (usually expressed in dollars per million Btu or $/mmBTU) with discounts associated with increased expenditures or operating costs for fuel storage, feeding, or ash-handling systems. The base energy cost of the existing primary fossil fuel must generally exceed $2 per million Btu for an RDF product to be competitive. This was one of the criteria used to evaluate the economic potential of a particular site.

2) Disposal Costs--Consistent with this approach, it is also important that the cost of existing and future waste disposal alternatives (primarily landfill) be sufficiently high to allow a competitive (lower) tipping fee at any future processing facility. As a rough guideline, a $10 per ton disposal cost was established for the site evaluations.

Commercialization Potential. The selection of sites for the Mobilizable Program should be based on the potential for implementing a full-scale, commercial follow-on facility. In addition to the technical and economic criteria mentioned, more subjective and often speculative considerations enter into determining commercialization potential. These factors are discussed below.

1) Environmental Regulations--Handling and disposal regulations affecting all types of solid waste currently being developed are likely to become more restrictive. The problem is already becoming acute near highly populated urban areas where acceptable landfill sites are being depleted and new sites are forced to locate some distance from the population center. Such conditions should spur increased consideration of waste-to-energy systems as a viable alternative.

At the same time, however, increasingly strict air pollution emissions standards affecting waste combustion facilities are likely to develop. For example, new standards for emissions of chlorides and heavy metals can be anticipated, and may have an impact on the proportion and extent of use of RDF as a supplemental fuel source. For purposes of combustion testing in connection with the Mobilizable Program, however, it is anticipated that a variance from local standards will be obtainable. In consideration of a follow-on commercial facility, such issues should be looked at in more detail for the specific location, equipment, and fuel mix involved.

2) Local Waste Planning--It is important that the status and direction of local waste management planning activities be considered when identifying and evaluating potential mobilizable test sites. While the Mobilizable Program is intended to encourage and accelerate the implementation of resource recovery projects, the presence of a local planning organization as a framework for investigating follow-on commercialization is an important criterion.

3) Potential Producer/User Interest--Assuming that markets can be secured for the purchase of RDF under long-term contracts, potential fuel producers must be available and have resources or recourse to procure, finance, and construct commercial facilities. Generally, interest on the part of potential producers would be marked by their willingness to share test program production costs and to participate in drafting purchase agreements. The interest of potential fuel purchasers, on the other hand, would be assessed by their willingness to commit manpower and equipment during testing as well as to assist in drafting fuel purchase agreements.

In each instance, both the potential fuel producer and fuel user must express a sincere willingness to participate fully in the Mobilizable Program, with the clear intention (but not legal commitment) of negotiating and eventually signing contracts upon the successful completion of the tests.

Approach

Having developed site-evaluation criteria, it was then necessary to identify potential test locations. Major boiler manufacturers and power industry trade groups and associations were contacted to obtain a listing of industrial boiler-fuel-user locations that met the criteria described. Associate member groups and other supporters of NCRR were contacted for additional inputs, and numerous publications were screened. A short briefing document describing the program and site-selection criteria was developed; this was presented to DOE and the U.S. Environmental Protection Agency (EPA) to determine if any of their planning grant recipients or contacts through government assistance programs might have a match of user/producer groups meeting basic criteria for consideration under the program. The resulting list was evaluated, and approximately 50 potential test locations identified.

For each test location, potential RDF producer and user groups were contacted to explain the program and to determine their interest in participating. Briefing documents describing the concept and intent of the program, its organizational structure, test parameters, and the general responsibilities and requirements were developed for producers and user groups that showed an interest in participating.

The briefing document forwarded to potential Production Agents included a "Draft Operating Agreement for the Mobilizable Production Facility" and a "Letter of Intent" to participate. These documents are included in Appendix A. The Draft Operating Agreement includes an Equipment Operating Agreement and a Production Schedule. The Operating Agreement covers two areas: (1) the operation and maintenance of the mobile production equipment and (2) the production of specified quantities of fuel for the test burns following a predetermined schedule. The Letter of Intent, which would be forwarded to DOE, essentially states that the prospective Production Agent understands the program and its particular responsibilities, and thereby intends to participate fully.

Prospective Burn Agents were sent draft agreements that described their responsibilities as participants in the program and established a set of general test criteria on which future fuel-contract negotiations would be based.

The "Draft Burning Agreement," included in Appendix B, was comprised of an "Agreement to Participate" in the program and a draft "Test Burn Schedule."

The Agreement to Participate outlined the agent's general responsibilities during the tests, and included a provision committing the fuel user to offering a purchase order for RDF if minimum combustion test criteria were met. The Test Burn Schedule specifies the quantities of RDF to be delivered and burned and an accompanying time frame for each, as well as transportation and storage requirements.

A second major part of the Draft Burning Agreement included provisions for a draft "Purchase Order" and "Fuel Price Adjustment and Purchase Order Termination Agreement." These documents, reproduced in Appendix B, are intended to serve as a basis for future contract negotiations between the fuel producer and user after presumed successful completion of RDF combustion testing.

Overall, the Draft Burning Agreement is a document intended to ensure that a potential Burn Agent would enter into final contract negotiations with a fuel supplier at the end of the test burn if all acceptance criteria were met.

Results

From the original list of 50 sites, roughly nine showed enough interest in the program to warrant additional consideration. The overall characteristics of eight boilers at these sites are provided in Table 1. Subsequent discussions centered around the particular situation at each location regarding existing waste and fuel supplies and costs; the climate for resource recovery in the area; the willingness of these groups to commit to the program; and, ultimately, the potential for success from these efforts.

The list was trimmed to nine firm candidate sites and, in the majority of cases, personal site visits were made by NCRR staff to brief those involved on the particulars of the program in an attempt to gain commitments from three to five producer/user groups to participate in the program.

The results of these efforts were surprising. In spite of continued interest, not one candidate would commit to participation in the Mobilizable Program; therefore, no firm test site locations were identified. Several factors contributed to the inability to secure signed Agreements to Participate from potential Production and Burn Agents.

Both groups expressed particular concern over the long projected leadtime to initiate testing after agreements would be signed. It was observed that, if the project were to proceed, at least two or three years would be required to finalize project funding, procure and construct the mobile equipment, perform shakedown testing, and locate the system at the first test location. Adding up time at the first several sites, it could probably be four to five years before the equipment would be brought to the last of the initial five sites. The agents were consequently reluctant to make a firm commitment to an uncertain

Table 1

Characteristics of Selected Phase I Boilers

No.	Boiler Manufacturer	Type	Design Steam Capacity (lb/hr)	Avg. Steam Flow (lb/hr)	Primary Fuel	Preferred RDF Type
1	Babcock & Wilcox (B & W)	Rotating Grate Stoker	65,000	30,000	Coal	4-in. RDF or d-RDF
2	B & W	Traveling Grate Spreader Stoker	200,000	150,000	Bark & Oil	4-in. RDF
3	B & W	Spreader Stoker	100,000	50-75,000	Coal	4-in. RDF or d-RDF
4	Union Iron	Spreader Stoker	180,000	60,000	Coal	d-RDF
5	Riley	Traveling Grate Spreader Stoker	100,000	90,000	Coal, Oil, & Gas	4-in. RDF
6	Combustion Engineering (CE)	Traveling Grate Spreader Stoker	300,000	240,000	Wood Waste & Oil	4-in. RDF or d-RDF
7	CE	Spreader Stoker	100,000	80,000	Coal	d-RDF
8	CE	Spreader Stoker	100,000	100,000	Bark	4-in. RDF or d-RDF

project that could possibly hinder planning or implementation of other programs. Considering the rapidly changing environment regarding energy availability and cost, and the pressures of waste disposal regulations, their reluctance becomes even more apparent.

In their reluctance to sign an Agreement to Participate, potential Burn Agents stressed the need to maintain as much flexibility as possible regarding any long-term fuel purchases. Current difficulties experienced by resource-recovery plants in achieving and maintaining consistent fuel specifications and production levels, and concern regarding potential boiler damage from corrosion were also cited. Uncertainties regarding future environmental restrictions (particularly stack emissions of chlorides and heavy metals) and hazardous waste disposal (particularly disposal of ash by-products) were raised as serious impediments to an agreement at one site. The costs of equipment modifications at the boiler site to facilitate storage, handling, and firing waste fuels had been presumed in the concept of the program to be donated "in kind" by the user. However, although specific costs were not developed for individual sites, potential users thought that, with the technical and economic uncertainties that existed, firm commitments could not be made.

User groups were also reluctant to sign Letters of Intent and other agreements to participate due to the strong language contained in the Draft Burning Agreement, which stated they were committing to contract for fuel from a producer group after the completion of successful combustion testing.

Potential fuel producers, although generally more inclined to commit to the project, expressed concerns regarding the processing equipment and its performance reliability. The costs associated with their involvement in the project did not appear to present any significant problems, although the potential financial risks involved in any follow-up commercial facility did.

Future Changes in Approach

For purposes of future planning, several changes in the approach are likely to generate greater interest in the program and to lead to possible commitments to participate. The most significant change involves providing a much more specific, near-term time frame for scheduling of equipment and testing at each site. As indicated, the long leadtime (three to five years) between procurement and delivery of equipment and site testing precluded commitments on the part of most potential participants. Most indicated they would be more inclined to participate if the mobile equipment were available on an immediate or near-term basis, thus facilitating their planning.

Although one intent of the mobilizable project was to encourage full participation by producer and user groups and to insist that they absorb some of the associated costs to reflect a realistic situation, more definitive estimates of the costs to be incurred by each group are necessary. The original program scenario did not specify, for instance, who was to pay for any required boiler modifications (equipment and installation) or to what degree the producer was responsible for fuel transportation costs. These and other questions must be addressed and answers specified before approaching these groups in the future.

Finally, it may be necessary to modify somewhat the language contained in the draft Operating and Burning Agreements. The clause committing the Burn Agent to sign a purchase order for RDF upon meeting established criteria during the test burns may, for example, have to be softened. This provision does not allow sufficient flexibility, and was viewed by the potential Burn Agents who reviewed it as implying too firm a commitment as a result of participation in the program. Rather, it should be assumed that, since the agent has, in fact, agreed to fully participate in the program, he is aware of an implied commitment and intends to participate in contract negotiations for the long-term purchase of fuel.

SECTION 3

PROGRAM MANAGEMENT

The initiation and concept development phase identified six principal groups or agents that would be closely involved in some aspect of the Mobilizable Program. Each agent would have specified duties and obligations to perform, and would be contractually responsible to DOE through contracts or subcontracts for fulfilling those duties as detailed in signed agreements.

Table 2 identifies the six agents and lists the primary responsibilities of each. Additional information is provided as follows.

The Program Coordinator serves as the prime contractor and as the program implementation and commercialization agent. This agent would be responsible for any necessary refinements in program concepts; would oversee the design, procurement, assembly, and shakedown of the mobile equipment system; would coordinate local RDF production and combustion test scheduling; would schedule and coordinate activities of all the agents participating in the program; would condense and collate all data gathered during testing; and would assist in follow-up discussions between potential fuel producers and users for commercial facilities.

The Program Coordinator will represent DOE's interests over the life of the program and would report back at regular intervals with updates regarding project scheduling, test results, equipment operation, and agent activities and performance. Essentially, this agent will provide for overall program control, monitoring, and reporting.

The System Equipment Contractor would perform under contract to the Program Coordinator and would be responsible for the final design and actual construction of the mobile equipment system. Based on the system and equipment design specifications developed in Section 4, a request for proposal would be issued by DOE to potential system equipment contractors. The contractor selected would have responsibility for finalizing detailed design drawings and specifications, procuring or manufacturing necessary component equipment items, assembling the system, and overseeing startup and shakedown of the equipment at a predetermined site. Upon acceptance of the equipment , the equipment would be disassembled and transported to the first test site. In addition to warranting the system, the System Equipment Contractor would be contracted to provide on-site technical, operational, and maintenance support and to train Production Agent personnel at each test location.

The Transportation Agent would perform under a subcontractor to the Program Coordinator and would be responsible for the site-to-site transport of the entire mobile equipment system. Transport would generally be over-the-road or by rail. The agent would prepare route plans and secure all necessary state and/or federal road permits for any oversize or overweight equipment.

The Production Agent, normally the municipal department or waste management company responsible for the waste collection in a particular city, would be responsible for the operation and maintenance of the mobile system at a particular test site, and would be committed to produce a specified quantity of RDF for combustion testing. The agent would be given a production schedule indicating a timetable for the production of specified quantities of fuel and its transportation to a storage site. Responsibility for storage could vary from site to site. Fuel sampling and analysis would be performed on a regular basis during production. The agent would be required to perform regular maintenance on the equipment and to provide an operations and maintenance log.

However, the cost of labor needed to assemble and operate the equipment and to perform fuel sampling would be assumed by the Production Agent.

Table 2

Program Management Structure

<u>Department of Energy</u>

- program sponsor

<u>Program Coordinator</u>

- project management
- advance planning and coordination
- oversee design, procurement, assembly and shakedown of mobile equipment system
- establish and coordinate RDF production and test burn schedules
- coordinate activities of other program agents
- collate test data and prepare final report
- assist in contract negotiations and commercialization efforts

<u>System Equipment Contractor</u>

- system and equipment final design
- equipment procurement; assembly and shakedown
- on-site training, operational and maintenance support
- equipment performance warranty

<u>Production Agents</u>

- operate and maintain mobile equipment
- produce specified quantities of RDF/d-RDF according to production schedule
- sample fuel and document activities
- provide equipment operation and maintenance log
- transport RDF to burn site

<u>Burn Agents</u>

- receive and store test fuel
- provide manpower and materials to perform RDF combustion testing according to test-burn schedule
- assist in fuel, stack emissions and ash sampling
- document and report test observations and preliminary results

<u>Transportation Agent</u>

- transport mobile equipment system
- secure necessary transportation permits
- provide advanced route planning and transport schedules
- provide required insurance coverage

<u>Test Agent</u>

- perform fuel sampling, analyses and reporting at production and burn sites
- perform stack emissions and ash sampling, analyses and reporting
- assist boiler operators during testing
- observe and document testing procedures
- collate and evaluate final test data

The agent would be expected to provide adequate liability insurance, closely follow all safety requirements, and conform to any state and local ordinances regarding operation of the mobile equipment.

Having agreed to participate in the program, the Production Agent would be required to sign some form of draft Operating or Production Agreement as described in Section 2 and illustrated in Appendix A.

The Burn Agent is the owner and/or operator of the boiler site at which the RDF combustion testing would be performed. The agent would be responsible for receiving the RDF and for providing adequate storage facilities. The labor and materials for metering, mixing, and firing RDF or d-RDF during the boiler tests would be presumed to be the responsibility of the Burn Agent. If there were capital equipment requirements to retrofit the boiler to fire the RDF (see Section 5), the costs for engineering, procurement, installation, and removal would be negotiable The Burn Agent would assume liability for any boiler damage or downtime experienced in connection with the tests. The agent would assist the Program Coordinator in developing a test-burn schedule and an operational plan that the agent would be expected to follow at all times. The schedule would specify test dates, duration, blends, and quantities of fuel to be burned as well as boiler operating conditions.

The agent would be required to provide personnel to assist in data-taking during the tests, monitor system operations, and note any discrepancies in unit operation.

Having agreed to participate in the program, the Burn Agent would be required to sign a draft Burning Agreement as provided for in Section 2 and detailed in Appendix B.

The Test Agent would be responsible for sampling and monitoring selected emissions from the boiler stack during combustion testing as well as for performing fuel- and ash-sampling and analyses. It is presumed that the same Test Agent, under contract to the Program Coordinator , would perform these services at all the test sites. The Test Agent would work closely with both the Production and the Burn Agent in sampling the RDF and primary fuels and would work with the Burn Agent in determining proper sampling points, setting up instrumentation, coordinating personnel during the tests, and visually observing and documenting boiler operation. Typically, the agent would analyze boiler emissions for particulates, SO_x, NO_x, O_2, CO_2, CO, HC, Pb, Cℓ, and opacity, all of which are of special concern when burning refuse fuels. Bottom ash and flyash would be regularly sampled. The Test Agent would also assist the Program Coordinator in compiling and evaluating test results.

SECTION 4

RDF PRODUCTION AND FUEL FEED SYSTEMS: PROCESS CONFIGURATIONS AND EQUIPMENT SPECIFICATIONS

Introduction

The concept of a mobile municipal solid waste processing system to produce refuse-derived fuels implies a totally self-contained and transportable (over-the-road) system that can be assembled and operated at a test location to produce a limited quantity of fuel and that can then be disassembled and transported to subsequent test sites. A mobile system to meter and feed RDF into the test boilers is also provided as part of the program.

In addition to major component pieces comprising the MSW processing and fuel feed systems, the mobile system must include support equipment such as a portable electrical generator, material conveyors, control systems, spare parts and tools. Other items necessary for the test program, but not included in the mobilizable system, i.e., front-end loaders and transfer trailers, are assumed to be supplied on a lease basis at each of the test locations.

This section of the report will provide design and performance parameters and specifications for several recommended RDF production systems, as well as the estimated costs associated with each. Process flow schematics and mass balances for the production of shredded RDF and d-RDF are included. Several portable RDF boiler feed systems designed and operated in the past several years are considered in order to determine their applicability to the Mobilizable Test Program.

System Design Criteria and Limitations

The mobilizable system is intended to be totally self-contained and transportable, capable of handling unprocessed municipal solid waste to produce shredded RDF and d-RDF. It is anticipated that the equipment would be transported to and assembled at a local landfill or transfer station where sufficient quantities of fuel would be produced to conduct several boiler combustion tests. At the completion of testing, the equipment would be disassembled and moved to the next test site.

Initial evaluations from Phase I identified several parameters around which the mobile system should be designed. They concerned primarily fuel type, production capacity, yield, and limitations on the equipment size, construction, and costs.

Fuel Types. One of two types of fuel will be produced at a particular location, depending on the design characteristics of the test boiler and the existing primary fuel source. In assessing the design characteristics of industrial-sized boilers most suitable for combustion testing as part of this program (evaluated in detail in Section 5), it was determined that coarse (4 inch size) RDF and d-RDF would be required. Most of the boilers considered in this program utilize a spreader-stoker firing arrangement in which a percentage of the fuel burns in suspension, with the remaining portion combusted on a grate. Coarse RDF and d-RDF can be readily burned in these systems with, generally, few modifications. The initial evaluations had recommended that a third fuel type, fine RDF, also be produced. A fine RDF product is required only in boilers that utilize a full suspension firing arrangement without a grate to combust heavier material. Such unit designs are not suited to the mobilizable program.

Table 3 illustrates typical specifications for the RDF and d-RDF recommended for the program as well as for typical stoker-coal and wood-waste fuels.

Capacity. The system input capacity of 8 tons per hour (tph) of MSW and a production capacity of at least 3 tph (of RDF or d-RDF) is controlled by limitations on the size,

Table 3

Typical Fuel Analysis

	Stoker Coal[1]	Wood[2] (bark)	RDF[3]	d-RDF[3]
HHV (dry wt%)	13,800	8,000-9,000	5,500-6,000	5,500-6,000
Volatile	37%	70-75%	50-60%	50-60%
Moisture	1.8%	50%	15-25%	15-20%
Ash	6.6%	3-5%	15-20%	15-20%
Density	50-60 pcf	10-15 pcf	3-6 pcf	30-40 pcf
Particle Size	90% < 1.25 in. 30% < 0.25 in.	100% < 4 in. 95% < 2 in. 50% < 1/2 in.	4 in. nominal	100% < 2 in.

[1]West Virginia seam coal (wet basis). Source: CE Fueling Burning & Steam Generating Handbook, Combustion Engineering, Inc.

[2]Average of several bark fuels (dry basis). Source: Steam: Its Generation and Use, Babcock & Wilcox Co.

[3]National Center for Resource Recovery, Inc.

number, and operational complexity of the process equipment. At each test site, RDF or d-RDF will be produced at the rate of 3 tph until sufficient quantities of fuel are available to complete the test.

MSW:RDF Yield. RDF yield is defined as the final RDF product output reported as a percentage of the total incoming waste flow. In designing a mobile processing system, the primary concern is production of fuel representative in quality to that produced by a future, permanent follow-on facility (accounting for seasonal variations in waste and, therefore, fuel properties). Due to obvious technical and operational limitations on the mobilizable equipment, more of the combustible fraction will be sacrificed as residue in a mobile system than in a permanent facility, and the RDF yield will be correspondingly lower.

Physical Size. Size and weight of the mobile system is an important design constraint since the equipment is to be trailer-mounted and transported over existing primary and secondary roads. Although federal and local highway restrictions do vary from state to state, they generally fall within the following parameters:

weight - 40 to 60 tons (gross)

length - 55 to 70 ft

width - 8 ft to 10 ft maximum

height - 13 ft 8 in. to 17 ft

Permits to exceed these limits are generally available from individual states at a nominal cost. Required permits would be obtained by the Transportation Agent as part of its contractual responsibilities. Wherever possible and practical, each piece of mobile equipment will conform to the minimum size restrictions indicated above (i.e., 40-ton weight, 55-ft length, 8-ft width, 13-ft-8-in. height).

Safety and Environment. The major hazards encountered when processing MSW are the danger of explosions and dust and noise. The relatively low system capacity and effective inspection of the infeed waste flow to remove hazardous materials should minimize the explosion potential. Necessary care must be taken in designing and operating the equipment so as to minimize worker proximity to the shredder. Since the equipment will probably be located outdoors, noise should not pose a serious problem. Other than providing enclosures to contain dust, no special dust-control equipment is specified.

Capital Costs. By keeping the design of the system as simple as possible, and by utilizing commercially available equipment, capital costs can be minimized. Estimated capital costs for the recommended production systems (1981 dollars) will be detailed later in this section.

Reliability and Maintainability. Equipment reliability is considered a critical design consideration. The system will be a highly visible demonstration of resource-recovery technology, operated in the open and in the potentially harsh environment of a landfill. Any serious discontinuity of the tests due to disruptions in fuel production will be reflected in program delays, higher program costs, and, very likely, skepticism on the part of fuel producers and users regarding the feasibility of a successful resource-recovery operation in the future. However, the nature of a mobile system unfortunately does not allow for the flexibility of oversizing equipment and providing system redundancy to account for all potential operational and maintenance problems.

In designing the mobilizable system, therefore, efforts must be made within the limitations discussed to provide a system that is reliable in operation, capable of being operated and maintained in the field, and capable of withstanding several years of demanding use involving assembly, disassembly, and transportation.

Recommended Fuel Production Systems

A major intent of the research in Phase I, in addition to conceptualizing the Mobilizable Program, was to develop and evaluate potential RDF production systems. The Phase II research was intended to build upon and expand those initial concepts and to develop detailed process flow arrangements and equipment design specifications on which future requests for proposals could be based.

A total of 12 potential RDF and d-RDF production process flow arrangements were developed in Phase I, as illustrated in Table 4. They essentially represent two distinct

Table 4. Initial Process Flow Diagrams from Phase I

System	Permutation	Process Flow
1	(Recommended)	Trommel--Magnetic Separator--Shredder--Pellet Mill
	A	Trommel--Magnetic Separator--Shredder--Air Classifier--Pellet Mill
	B	Shredder--Trommel--Magnetic Separator--Secondary Shredder--Air Classifier--Pellet Mill
	C	Shredder--Trommel--Magnetic Separator--Secondary Shredder--Pellet Mill
	D	Flail Mill--Trommel--Magnetic Separator--Shredder--Pellet Mill
	E	Flail Mill--Trommel--Magnetic Separator--Shredder--Air Classifier--Pellet Mill
2	(Alternate)	Shredder--Air Classifier--Magnetic Separator--Pellet Mill
	A	Shredder--Air Classifier--Magnetic Separator--Trommel--Pellet Mill
	B	Shredder--Air Classifier--Magnetic Separator--Secondary Shredder--Pellet Mill
	C	Shredder--Air Classifier--Magnetic Separator--Secondary Shredder--Trommel--Pellet Mill
	D	Flail Mill--Air Classifier--Magnetic Separator--Secondary Shredder--Pellet Mill
	E	Flail Mill--Air Classifier--Magnetic Separator--Secondary Shredder--Trommel--Pellet Mill

approaches to processing municipal solid waste; a (1) "recommended system" and (2) "alternate system" were presented, as were five permutations associated with each.

The final recommendation for production systems and equipment design specifications from Phase II, as presented here, were developed after evaluating the information from Phase I and after subsequent additional research into the design and performance of available equipment.

Two processing arrangements were finalized and are recommended for the Mobilizable Program: an <u>RDF Production System</u> and a <u>d-RDF Production System</u>. The first is designed to produce a coarse, shredded RDF material; the second, a densified RDF product. The two systems, based on the design criteria developed earlier, utilize many of the same components.

Equipment process flow and mass balance schematics were developed for each system. For each equipment item in the processing train, a set of Equipment Design Specifications were developed for use as a basis for future evaluations and preparation of equipment procurement documents. In most instances, these design specifications were developed based on information and specifications provided by equipment manufacturers contacted during the first and second phases of the program. The specifications and price quotations received from manufacturers of specific equipment items have been included in Appendix C of this report.

<u>RDF Production System.</u> Figures 2 and 3 illustrate the equipment process flow and material mass balance for the recommended mobilizable RDF production system. The Equipment Design Specifications for individual processing equipment items are provided in Tables 5 through 10 and in Figure 4. The design specifies an input flow of 8.0 tph of municipal waste and an output flow of 3.8 tph of shredded RDF in either a loose, compacted form or in more highly compacted bales.

Total yield of this sytem is estimated to be approximately 47.5 percent. As stated earlier, obtaining a high yield from the mobile system is not a major consideration; rather, obtaining a representative fuel product and operational reliability is of prime concern.

Incoming MSW is first visually inspected; large, bulky objects (carpets, pallets, etc.) and potentially hazardous materials (solvent cans, gas bottles) are removed by hand. A front-end loader feeds waste at a controlled rate into a receiving hopper and onto the infeed conveyor to the trommel.

The trommel, a rotating, cylindrical screening device, is the first phase of waste processing. It is intended to remove a majority of the noncombustible material from the waste stream. Extensive testing and evaluation at existing resource-recovery facilities indicates that the trommel is effective in reducing the final ash content of the fuel product as well as significantly reducing wear on downstream size-reduction equipment.

As the screen rotates, lifters welded to the inside of the shell lift and then drop the waste, tearing open bags and breaking glass containers. The broken glass, sand, dirt, and other fine materials along with some cans, paper, and other waste pass through 4.5-in. circular holes in the trommel shell and are conveyed away from the trommel and discarded. This waste fraction, referred to as the trommel "undersize" material, contains most of the noncombustibles.

The material larger than 4.5 in. that does not pass through the trommel holes is referred to as "oversize" material. This material, comprising approximately 50 percent of the incoming waste stream, contains primarily paper and plastics and forms the fuel fraction. It is discharged from the trommel end and conveyed to the magnetic separator.

The magnetic separator, located directly downstream from the trommel and positioned over the trommel oversize discharge conveyor, removes ferrous metals from the process stream. In commercial waste-processing applications, the device is utilized to produce a saleable ferrous product. However, in the mobile system, it is intended to reduce the quantity of material to and wear in the shredder as well as lower the noncombustible content of the fuel product.

The process stream is reduced to its final particle size in the shredder. The shredder is capable of producing the 3- to 4-in. nominal-sized RDF suitable for direct firing in a spreader-stoker boiler. The shredder product size can be changed by modifying the configuration of hammers within the shredder.

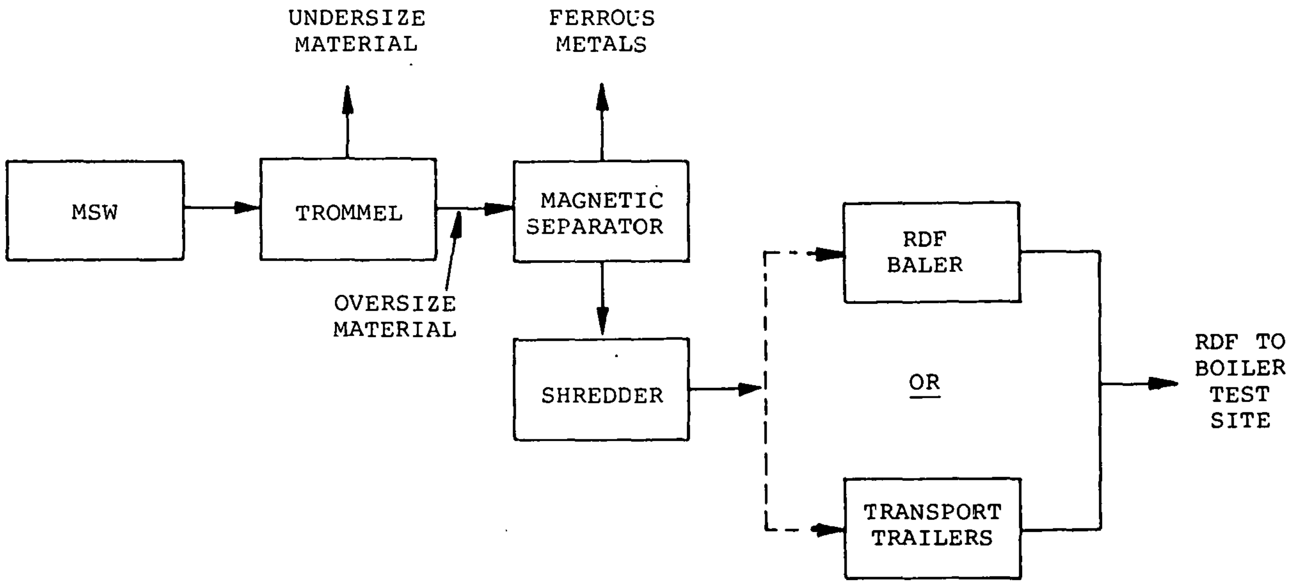

Figure 2. Recommended RDF Production System Process Flow Schematic

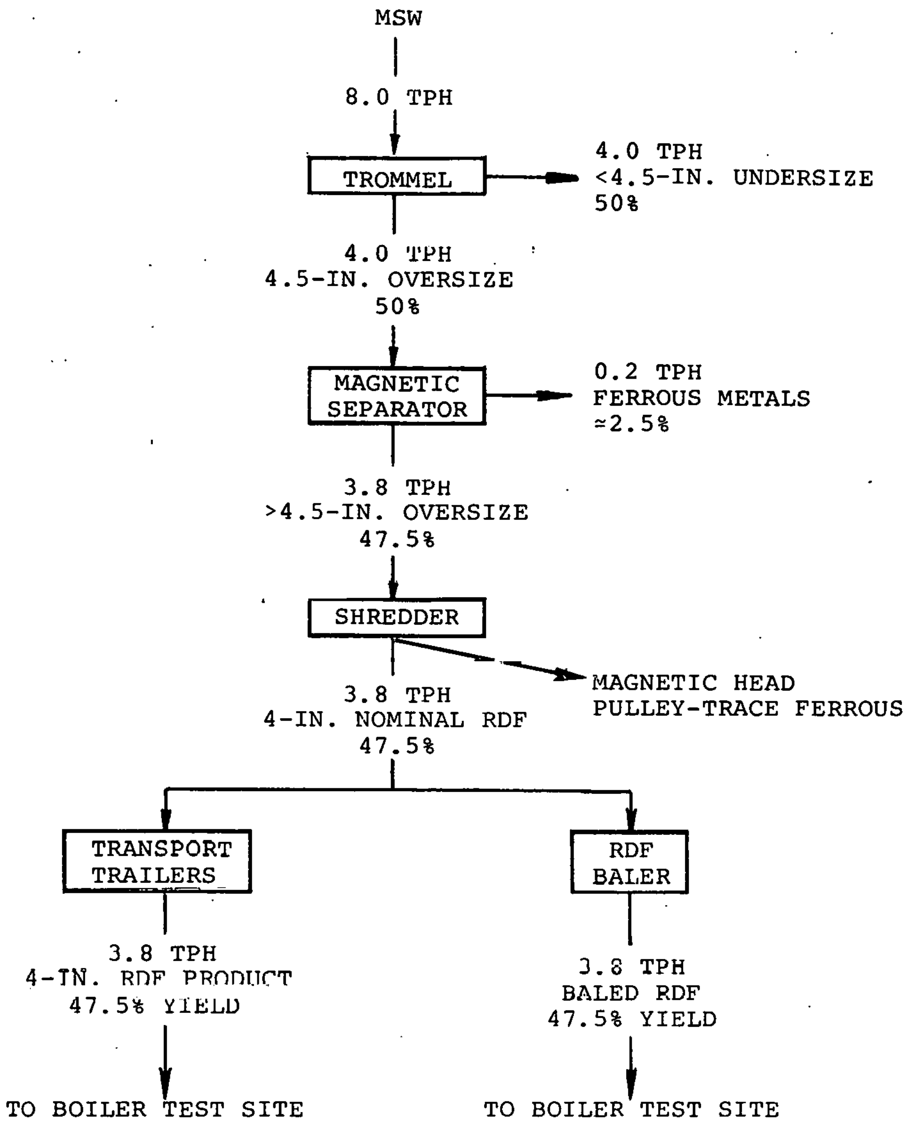

Figure 3. RDF Production System Material Mass Balance

Table 5

Equipment Design Specification No. 1

Mobile Trommel Screen

- Purpose: break open bags and containers and screen out non-combustibles such as glass, sand, dirt and some metals
- Location: first piece of equipment in RDF and d-RDF production process flow
- Type: trailer mounted rotary screen with lifters, 4.5-in. circular holes
- Material Input: 8 TPH of MSW (bulky objects removed)
- Material Output: (1) 4 TPH oversize (80% > 4½ in., 15% ash, <2.5% ferrous, <0.5% non-ferrous)

  (2) 4 TPH undersize (<4½ in.)
- Design Capacity: 8 TPH
- Dimensions: restricted by trailer size

  1) length: ~20 ft

  2) diameter: 8 ft Inside Diameter (min)
  10 ft Outside Diameter (max)

  3) height: 13.5 ft (max) mounted on trailer
- Power Requirements: ~25 hp (trommel drive only)
- Rotational Speed: variable
- Angle of Declination: 0° - 15°
- Screen: fixed, with 4.5-in. circular holes and lifters
- Unit to Include:

  1) undersize material hopper

  2) dust enclosure

  3) motor and drive system

Table 5 (Cont'd)

4) motor starters and electrical controls; NEMA type 12 enclosures

5) MSW infeed conveyor with sidewalls and receiving hopper (Conveyor No. 1, Fig. 4)

6) undersize material hopper discharge conveyor (Conveyor No. 2, Fig. 4)

7) undersize material hopper transverse discharge conveyor (Conveyor No. 4, Fig. 4)

8) oversize material discharge conveyor with sidewalls (Conveyor No. 3, Fig. 4)

9) 40 ft drop-back trailer

- Estimated Cost: based on manufacturer's quotations, Appendix C

$140,000 - trommel screen with auxiliary equipment as above (does not include 40 ft trailer)

Table 6

Equipment Design Specification No. 2

Magnetic Separator

- Purpose: remove ferrous metals from trommel oversize material stream prior to shredding
- Location: approximately 9 in. above head pulley of trommel oversize material discharge conveyor
- Type: in-line (or transverse) self-cleaning belt-type electromagnet
- Material Input: 4.0 TPH (>4.5-in. trommel oversize material)
- Material Output: 3.8 TPH oversize material

  0.2 TPH ferrous metals (with contaminants)
- Design Capacity: 6 TPH
- Efficiency: >90% ferrous removal (product contamination not specified)
- Power Requirements: ~2.0 HP (belt drives)
- Unit to Include:

  1) cleated rubber belt
  2) silicon rectifier
  3) motor and drive system
  4) motor starter and electrical controls; NEMA type 12 enclosures
  5) ferrous product discharge conveyor (Conveyor No. 5, Fig. 4)
- Estimated Cost: based on manufacturer's quotations, Appendix C

  $7,000 - elcctromagnet with rectifier and controls
  $5,000 - support structures and ferrous discharge chute (does not include ferrous product discharge conveyor
  $12,000

Table 7

Equipment Design Specification No. 3

Mobile Shredder

- Purpose: size reduction (either coarse or fine shred) of trommel oversize material
- Location: downstream of magnetic separator
- Type: trailer mounted refuse shredder, diesel or electric drive
- Material Input: 3.8 TPH (>4.5-in. trommel oversize material with ferrous metals removed)
- Material Output: 3.8 TPH of 4-in. nominal coarse shred RDF, or

  3.8 TPH of 1-1/2-in. nominal fine shred RDF
- Design Capacity: 8 TPH
- Dimensions: (restricted by trailer size)
  1) length: 40 ft (max)
  2) width: 10 ft (max)
  3) height: 13.5 ft (max)
- Power Requirements: approx. 200 hp (shredder shaft drive)
- Hammers: hard-faced steel, interchangeable
- Unit to Include:
  1) motor and drive system (electric motor preferred)
  2) motor starter and electrical controls; NEMA type 12 enclosures
  3) overspeed and zero-speed sensors and cutoff

Table 7 (Cont'd)

4) infeed conveyors with receiving hopper (Conveyor Nos. 7 and 8, Fig. 4)

5) shredder discharge conveyors (Conveyor Nos. 9 and 10, Fig. 4)

6) interchangeable hammers for product sizing and maintenance

7) low-boy trailer

- Estimated Cost: based on manufacturer's quotations, Appendix C

  $280,000 - shredder with auxiliary equipment as above (does not include low-boy trailer)

Table 8

Equipment Design Specification No. 4

RDF Baler

- Purpose: compact 4-in. RDF product into bales for ease of transport and storage at boiler site
- Location: downstream of shredder in RDF production process flow
- Type: trailer-mounted, horizontal baler with hydraulic drive
- Material Input: 3.8 TPH (4-in. RDF at 4 to 6 lb/ft^3
- Material Output: 3.8 TPH baled RDF
- Design Capacity: ~5 TPH
- Bale Size & Weight: estimated 6 ft x 4 ft x 3 ft (72 ft^3)
  ~1500 lb/bale (21 lb/ft^3)
- Power Requirements: ~30 hp
- Baler Machine Size: ~19 ft long x 5 ft wide x 6 ft high
- Unit to Include:
  1) motor and drive system
  2) motor starter and electrical controls;- NEMA type 12 enclosure
  3) infeed hopper
  4) automatic cycling and bale control features
  5) roller-type discharge conveyor
  6) 35-ft drop-back trailer
- Estimated Cost: based on manufacturer's quotations, Appendix C

  $30,000 - horizontal baler with auxiliary equipment as above (does not include 35-ft trailer)
  $ 1,000 - roller conveyor discharge
  $31,000

Table 9

Equipment Design Specification No. 5

Portable Generator System

- Purpose: provide onsite electrical power generation for various equipment systems
- Location: onsite at RDF production area
- Type: trailer-mounted, fully enclosed diesel engine electric generator
- Power Rating: depending on mobile system electrical

  1) 500
  2) 600
  3) 750

- Engine Specifications:

	hp	Fuel consumption (est)
1) 500	750	38 gal/hr
2) 600	900	45 gal/hr
3) 750	1100	55 gal/hr

- Generator Specifications: all sizes

  1) 3 phase, 60 Hz, 240/480 or 230/460 VDC

- Unit to Include:

  1) full motor cover with cooling fan

  2) water cooled, turbocharged diesel engine

  3) control system

- Estimated Cost: based on manufacturer's quotations Appendix (does not include transport trailer)

  1) 500: $95,000
  2) 600: $135,000
  3) 750: $165,000

Table 10

Equipment Design Specification No. 6

Conveyor Systems

Conveyor No.	Description	Type	h.p.	Width (in.)	Length (ft)	Cost
1	trommel infeed conveyor	Flat, cleated rubber belt w/sides	≃2[a]	48	12	c/
2	trommel undersize discharge conveyor	Flat, rubber belt	≃1	36	13.5	c/
3	trommel oversize discharge conveyor	Flat, cleated rubber belt w/sides	≃1½	48	8	c/
4	trommel undersize transverse discharge conveyor	Trough, rubber belt	≃1	36	8	c/
5	ferrous product discharge conveyor	Trough, rubber belt	≃½[b]	18	8	$3,800
6	trommel-to-shredder connecting conveyor	Trough, rubber belt w/hood	≃1[b]	36	15	$10,700
7	shredder loading conveyor	Flat, cleated rubber belt	-	42	11	d/
8	shredder infeed conveyor	Flat, rubber belt	2	48	16.5	d/
9	shredder discharge conveyor	Flat, rubber belt	1½	36	9.75	d/
10	shredder transverse discharge conveyor	Flat, rubber belt	1	30	10	d/
11	shredder-to-RDF baler/RDF transfer trailer/nonferrous separator, connecting conveyor	Trough, rubber belt w/dust hood	≃1½[b]	24	20	$8,200
12	nonferrous separator-to-densifier connecting conveyor	Trough, rubber belt	≃½[b]	18	10	$4,100
13	nonferrous separator rejects discharge conveyor	Trough, rubber belt	≃½[b]	18	8	$3,800
14	densifier discharge conveyor	Trough, rubber belt	≃½[b]	18	12	$4,300

[a]Indicates approximate h.p.

[b]External power required.

[c]Included in cost of trommel screen; Specification #1.

[d]Included in cost of shredder; Specification #3.

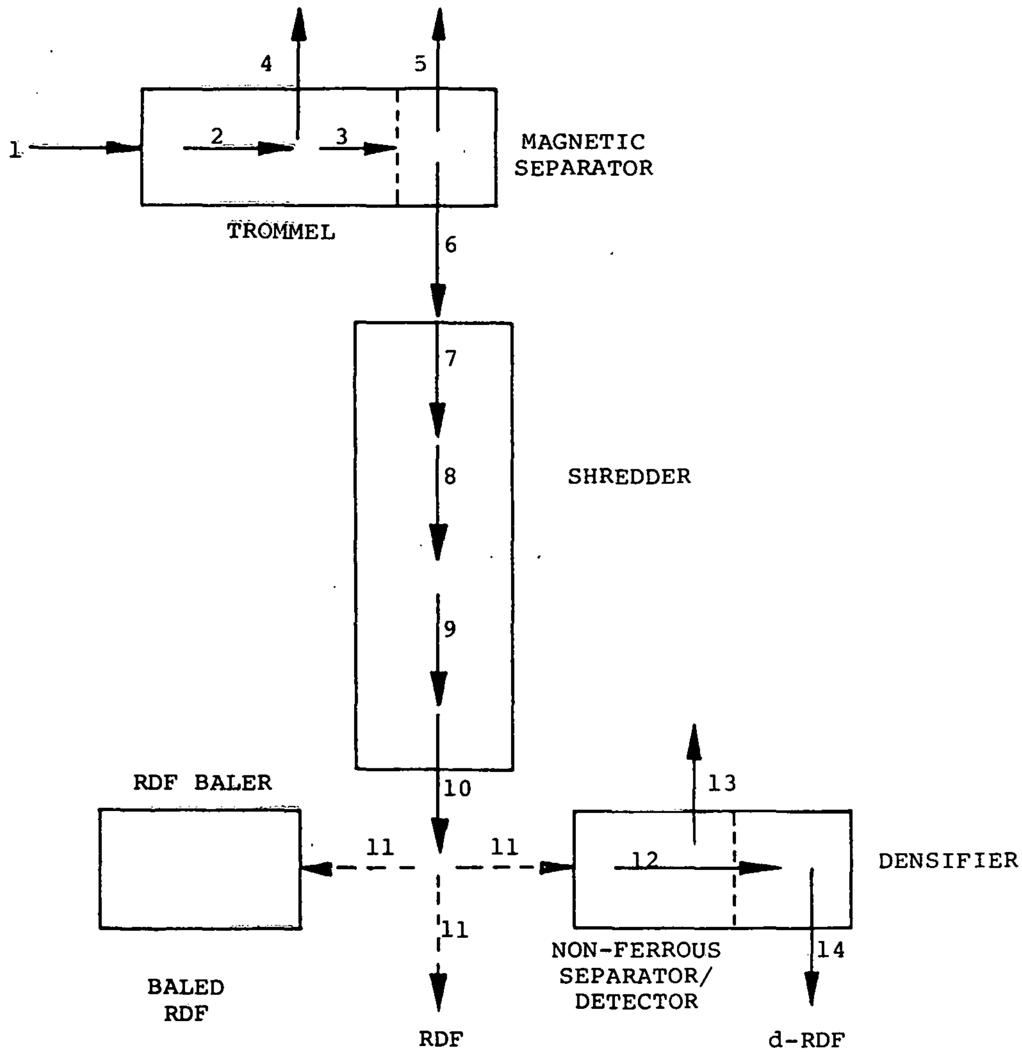

Figure 4. RDF/d-RDF Production Systems Conveyor Layout (see Equipment Design Specification No. 6, Table 10, for conveyor details)

approaches to processing municipal solid waste; a (1) "recommended system" and (2) "alternate system" were presented, as were five permutations associated with each.

The final recommendation for production systems and equipment design specifications from Phase II, as presented here, were developed after evaluating the information from Phase I and after subsequent additional research into the design and performance of available equipment.

Two processing arrangements were finalized and are recommended for the Mobilizable Program: an RDF Production System and a d-RDF Production System. The first is designed to produce a coarse, shredded RDF material; the second, a densified RDF product. The two systems, based on the design criteria developed earlier, utilize many of the same components.

Incoming MSW is first visually inspected; large, bulky objects (carpets, pallets, etc.) and potentially hazardous materials (solvent cans, gas bottles) are removed by hand. A front-end loader feeds waste at a controlled rate into a receiving hopper and onto the infeed conveyor to the trommel.

The trommel, a rotating, cylindrical screening device, is the first phase of waste processing. It is intended to remove a majority of the noncombustible material from the waste stream. Extensive testing and evaluation at existing resource-recovery facilities indicates that the trommel is effective in reducing the final ash content of the fuel product as well as significantly reducing wear on downstream size-reduction equipment.

As the screen rotates, lifters welded to the inside of the shell lift and then drop the waste, tearing open bags and breaking glass containers. The broken glass, sand, dirt, and other fine materials along with some cans, paper, and other waste pass through 4.5-in. circular holes in the trommel shell and are conveyed away from the trommel and discarded. This waste fraction, referred to as the trommel "undersize" material, contains most of the noncombustibles.

The material larger than 4.5 in. that does not pass through the trommel holes is referred to as "oversize" material. This material, comprising approximately 50 percent of the incoming waste stream, contains primarily paper and plastics and forms the fuel fraction. It is discharged from the trommel end and conveyed to the magnetic separator.

The magnetic separator, located directly downstream from the trommel and positioned over the trommel oversize discharge conveyor, removes ferrous metals from the process stream. In commercial waste-processing applications, the device is utilized to produce a saleable ferrous product. However, in the mobile system, it is intended to reduce the quantity of material to and wear in the shredder as well as lower the noncombustible content of the fuel product.

The process stream is reduced to its final particle size in the shredder. The shredder is capable of producing the 3- to 4-in. nominal-sized RDF suitable for direct firing in a spreader-stoker boiler. The shredder product size can be changed by modifying the configuration of hammers within the shredder.

The design and performance specifications developed for the shredder system were based on data from an existing trailer-mounted shredder system (see Appendix C). Several of these machines were manufactured for the U.S. Air Force and, more recently, for use in the United Kingdom. The production and operational experience gained on this equipment would prove to be valuable in the design and specifications of the shredder and other mobile equipment proposed for this program.

From the shredder, the RDF product passes over a permanent magnet located at the head pulley of the shredder discharge conveyor to remove any residual ferrous material.

At this point, the RDF product can be loaded into transfer trailers (either loose or compacted) or pressed into bales for shipment to storage at the boiler test site. The particular methods for handling and storage will be determined by the availability of fuel storage space or facilities at the boiler site. It may be necessary to store as much as 350 to 400 tons of RDF at one time to ensure the continuity of combustion testing. A large enclosure (approximately 100 ft x 90 ft x 20 ft) would be necessary to store 400 tons of RDF in an uncompacted state (assuming RDF at 6 pounds per cubic foot ("pcf") and piled mechanically to a height of 15 ft).

A more viable alternative would be to compact the RDF into bales at the production site, and to store the bales outdoors under a cover or in an enclosure at the boiler site.

A horizontal baler, utilized primarily in paper recycling industries, can compact RDF into 72 ft^3 bales weighing as much as 1500 to 1800 pounds (bulk density ≈ 23 pcf). The bales, held together with wire or plastic straps, would be loaded onto trailers and shipped to the test site. The bales can be neatly stacked, greatly reducing storage requirements. An area 70 ft x 50 ft will be required for 400 tons of baled RDF stacked 10 ft high. To prepare the baled RDF for feeding into the boiler, a de-baling machine must first be employed to break apart the bales and recondition the fuel to its normal unagglomerated, loose state. A more detailed description of an existing RDF de-baling and boiler feed system will be described later in this section.

Densified-RDF Production System. Figures 5 and 6, respectively, illustrate the equipment process flow and material mass balance for the recommended d-RDF production system. Note that the system is identical to that of the RDF production process with two exceptions. A nonferrous metals separator/detector is included and an RDF densifier replaces the compactor/baler. Tables 11 and 12 present the Equipment Design Specifications for these two pieces of equipment.

As stated previously, the particle size of the shredder output material can be varied by modifying the hammer configuration within the unit. It will be necessary to reduce the trommel oversize material to a nominal 1 1/2-in. particle size for proper operation of the densifier. Based on discussions with the shredder manufacturer, this reduction in size appears feasible with little or no reduction in shredder capacity.

The 1 1/2-in. shredded material is conveyed to a nonferrous metal separator or detector for removal of any remaining nonferrous metals and other tramp materials. These materials, although they comprise a very small percentage of the waste stream, can cause excessive densifier wear and plugging as well as potentially severe machine damage. Air classifiers and air knife-type separators are commercially available, and DOE is supporting a development program on a new design for a tramp material separator for specific application to a processed fuel fraction such as the one required for this program. As an alternative, a metal detecting device, designed to signal the presence of tramp metals that could be removed by hand, might be considered.

The prepared material is conveyed from the nonferrous separator to a densifier. The machine most commonly used at present to densify RDF is a pellet mill. Incoming RDF is conveyed by a series of screw-flight conveyors into the pelletizing chamber. The material is pressed through a die with an array of circular holes (typically 1/2, 3/4, 1, or 1 1/4 inch diameter) by two or more rollers mounted in the die cavity. The pellets will break off in random lengths of generally 1/2 to 1 1/2 inch. Average bulk density is 35 to 40 pounds per cubic foot. It is important that the feedstock to the pellet be uniformly sized and have abrasive fines removed to avoid excessive wear and plugging. As mentioned, tramp materials, especially metals, can cause serious damage to die and roller assemblies. Large pieces of textiles can blind the die holes, resulting in reduced capacity and frequent stoppages. Several of these machines are currently utilized in demonstration or commercial-scale resource-recovery facilities.

A second type of densification machine that is commercially available produces densified material typically 1 1/4 in. square by 3 in. long. Incoming RDF is first conditioned by a series of spiked fluffing rolls that also act to meter and control material flow to the feed chamber. An auger forces material to the face of the die, where a large rotating presswheel forces it through a single row of individual square die assemblies. While this equipment appears to be less susceptible to plugging by textiles and other large materials than the pellet mill, the d-RDF product is typically lower in bulk density than that of the pellet mill, with average bulk density reported to be 25 to 30 pcf.

As it is produced, the d-RDF can be loaded into open-top trucks for each shipment to and storage at the boiler test site. The fuel is then readily mixed in existing bunkers or storage silos with coal or wood waste prior to feeding into the boiler.

Fuel Receiving, Metering, and Feed Systems

In addition to the fuel production systems, the program requires transportable equipment for metering and feeding fuel to the test-boiler unit. Equipment performance criteria and specifications are developed and presented in this section, and several feed systems previously used in various applications are reviewed to determine the potential for utilizing them in the Mobilizable Test Program.

System Design Criteria and Approaches. At each boiler test site location, it is anticipated that a total of approximately 750 tons of RDF or d-RDF will be utilized during

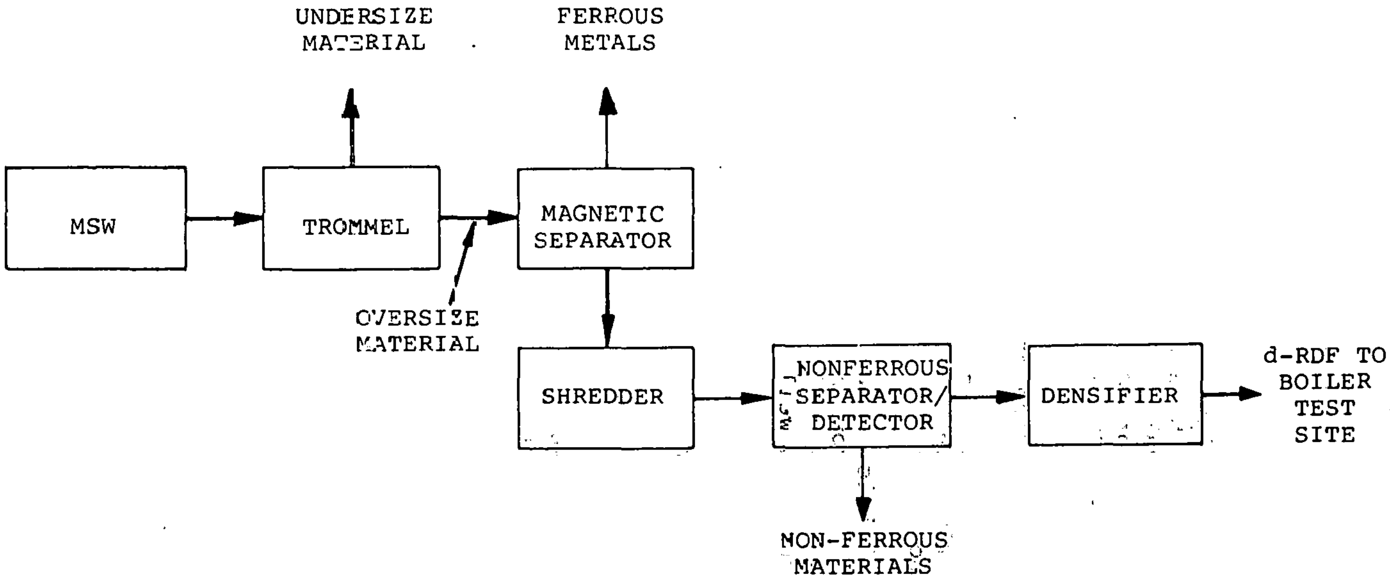

Figure 5. Recommended d-RDF Production System Process Flow Schematic

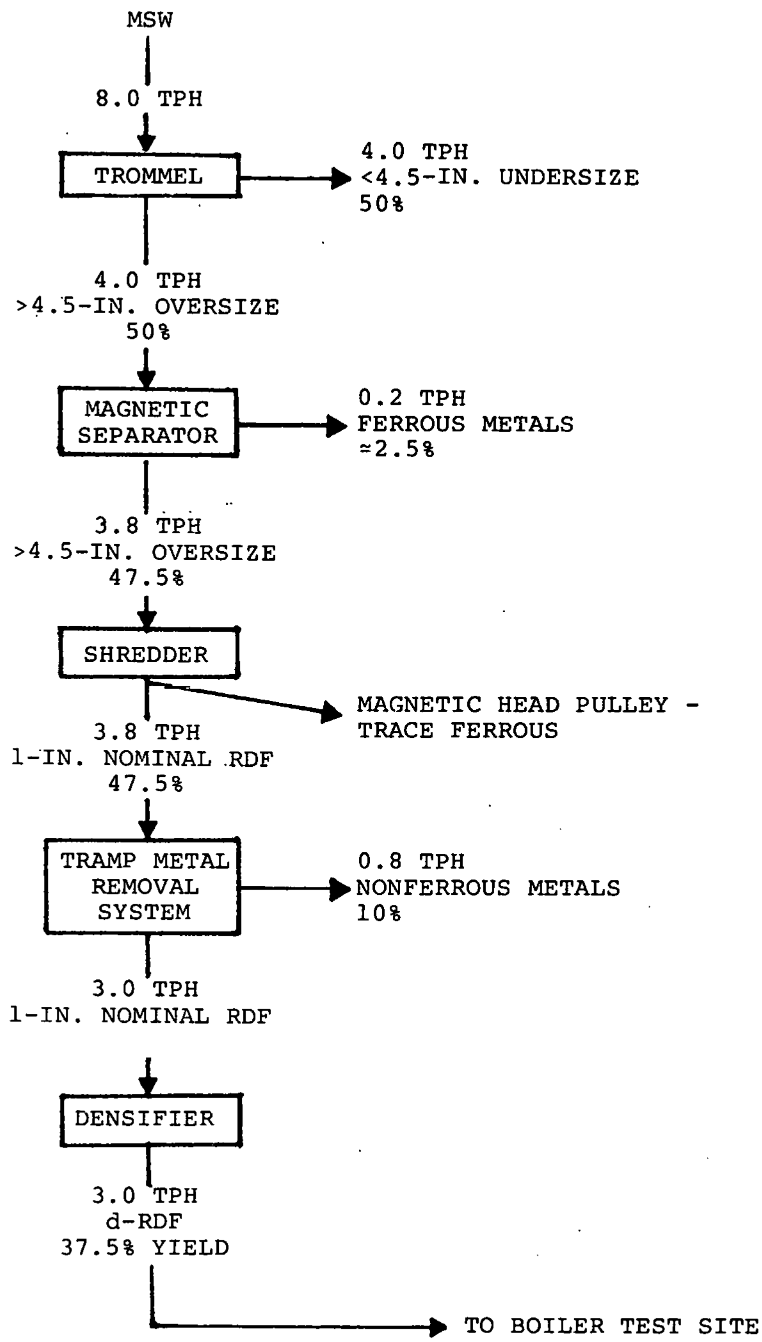

Figure 6. d-RDF Production System Material Mass Balance

Table 11

Equipment Design Specification No. 7

Tramp Metal Removal System

- Purpose: remove tramp nonferrous and remaining ferrous metals from process stream prior to RDF densification
- Location: downstream of refuse shredder in d-RDF production process flow
- Type: the actual design and operation of this system is yet to be finalized, non-ferrous metals and other tramp material will be removed either by mechanical or pneumatic separation or by hand-sorting
- Material Input: 3.8 TPH (1½-in. nominal size shredded trommel oversized material with ferrous metals removed)
- Material Output: (1) 3.0 TPH of 1½-in. RDF material for densification

  (2) 0.8 TPH of and other tramp materials
- Design Capacity: 6 TPH
- Power Requirements (est., if applicable): ~25 h.p.
- Unit to Include:

  1) motor and drive system (if applicable)

  2) motor starter and electrical controls (if applicable)

  3) materials handling conveyors (Conveyor Nos. 12 and 13, Fig. 4)
- Estimated Cost: based on NCRR estimate

  $75,000 - tramp metal removal system with auxiliary equipment as above

Table 12

Equipment Design Specification No. 8

RDF Densifier

- Purpose: densify finely shredded RDF into d-RDF pellets or cubes
- Location: downstream of nonferrous-metal-removal system in the d-RDF process flow only
- Type: trailer mounted extrusion-type pellet-mill or cubing machine
- Material Input: 3.0 TPH (1½-in. nominal RDF with ferrous and non-ferrous metals removed)
- Material Output: 3.0 TPH of d-RDF (minimum density 30 lb/ft^3, sized to be compatible for burning with stoker coal or wood chips)
- Design Capacity: 4.5 TPH
- Power Requirements: 1) ~225 h.p. for pellet-mill
  2) ~160 h.p. for cuber
- Unit to Include:

    1) motor starters and electrical controls; NEMA type 12 enclosures

    2) zero-speed cutoff and shear pin release system

    3) infeed hopper and metering device

    4) positive die feed system

    5) product output conveyor (Conveyor No. 14, Fig. 4)

    6) spare die and roller assemblies

    7) 40-ft drop-back trailer

Table 12 (Cont'd)

- Estimated Cost: based on manufacturer's quotations, Appendix C

  1) pellet-mill: $70,000 to $105,000 - mill with auxiliary equipment as above (does not include trailer, spare parts, or product output conveyor)

  2) cube machine: $100,000 - densifier with auxiliary equipment as above (includes trailer; does not include spare parts or product output conveyor)

  $5,000 - cost of dies

  $105,000

three individual test burns: three tests of 100, 250, and 400 tons each are anticipated. Although initial evaluations called for RDF utilization during the tests at blends of 10 to 30 percent by total heat input with the primary fuel, a maximum of 20 percent may be a more realistic figure.

Storage. In order to ensure the continuity of each combustible test and, therefore, the reliability and representativeness of the test data, it was determined that storage facilities large enough to handle up to 400 tons of fuel at one time should be available at the boiler site. Although this does present a significant fuel storage requirement, it is necessitated by the lower daily RDF production capacity of the mobile system (20 to 30 tons per day), compared to the total fuel combustion requirements (30 to 80 tons per day). It also eliminates the possibility of test interruptions due to inadequate or irregular shipments of fuel from the Production Agent.

Depending on the type of fuel to be stored (RDF or d-RDF), several alternatives are available.

Densified-RDF presents fewer storage problems. This material can be readily stored in a covered pile (tarp or building) for several weeks without serious degradation. Four hundred tons of d-RDF with a bulk density of 35 pcf can be stored in two sloped piles approximately 10 ft high, 75 ft long, and 30 ft wide.

Storage requirements for RDF present a more formidable problem. A covered space 100 ft long, 90 ft wide, and 20 ft high would be necessary to store 400 tons of uncompacted RDF to a height of 15 ft. Unless a building or similar enclosure of this size is available, temporary storage facilities will be required. The feasibility of utilizing an inflatable building (similar to those used to enclose tennis courts and swimming pools) was considered but eliminated due to the high initial cost and to the difficulty in assembly and disassembly. Storage in transfer trailers (preferably self-compacting), while the most convenient option, could require as many as 30 such trailers to store 400 tons of compacted fuel. Unless available at a particular site, the cost of purchasing or leasing these units would be prohibitive.

A more realistic approach would be to bale the RDF at the production site and to ship it for storage to the burn site. A rectangular pile of stacked bales approximately 70 ft long, 50 ft wide, and 10 ft high would be necessary to accommodate 400 tons. The bales would have to be broken apart and the RDF reduced to its original size before the fuel is fed to the boiler.

System Capacity. The fuel feedrate will depend on the size of the boiler, the duration of the test burn, and the amount of RDF utilized as a percentage of total unit heat input. To provide the flexibility necessary to meet the above conditions, the system should have the capability to receive, meter, and transport to the boiler from one to six tons of shredded RDF per hour.

Fuel Properties. The portable system is necessary to meter, transport, and feed shredded RDF to the boiler. Densified RDF is assumed to be readily mixed with the plant's primary fuel (coal or wood waste) in storage piles or fuel bunkers and fed to the furnace utilizing existing equipment.

Transportable. The feed system will be included as part of the mobilizable equipment and must, therefore, be totally transportable. When disassembled and loaded, its component pieces must permit the transport trailer to operate within legal size restrictions. Space constraints anticipated at the boiler sites facilitate the need for the system to be compact and flexible in design.

Review of Systems. Within the past five years, several portable systems for receiving, metering, and feeding RDF have been designed, built, and operated. They were utilized almost exclusively for test purposes, and the designs (or actual equipment, if available) could be adapted for use in the Mobilizable Program since they meet most of the design criteria specified in this report.

Two systems are particularly well suited to the program and will be described in more detail here: a mechanical RDF feed system built for Battelle Columbus Laboratories and tested at the Columbus, Ohio, Municipal Electric Co., and a pneumatic system designed to receive baled RDF and to feed a cement kiln at Canada Cement LaFarge, Ltd., Woodstock, Ontario. Two additional systems, one built by the Heil Co. for an installation at Prudhoe Bay, Alaska, and the other by Teledyne National for RDF combustion testing, are described briefly.

Battelle System. RDF combustion testing conducted by the Battelle Columbus Laboratories and sponsored by the Environmental Protection Agency, was performed at the Columbus, Ohio, Municipal Electric Plant between September 1974 and October 1977. RDF was burned at an average rate of 22 percent by total heat input (2.5 to 3.5 tph) with high sulfur stoker coal in a 150,000 lb/hr Riley traveling-grate spreader-stoker-fired boiler. The fuel was MSW shredded to 90 to 90 percent minus 4-in. material, then air-classified to remove noncombustibles. A layout drawing of the fuel receiving and feed system at the power plant is shown in Figure 7.

Shredded RDF was unloaded from transfer trailers into a push pit that serves as a fuel storage and retrieval system. The push pit, a modified transfer trailer with a hydraulic ram to feed RDF from the pit in a continuous stream, was extended to incorporate a fuel reclamation system. The reclaim system, illustrated in Figure 8, consisted of several "beater bars" and a 16-in.-diameter feed screw. The beater bars acted to break up the advancing wall of material from the push pit and dropped it into the feed screw trough. The screw then moved material into a transfer hopper. A 14-in.-diameter variable-speed screw conveyor then redirected the flow from the transfer hopper onto a 30-in.-wide belt conveyor, which conveyed the RDF to a transfer system at the boiler. The transfer system split the flow of material from the conveyor in half and directed it into two 16-in.-diameter augers. The augers transferred the RDF horizontally to gravity feed chutes and into two air-swept distributor spouts that fed the furnace, as illustrated in Figure 9. Each auger and feeder was capable of handling the total fuel flow from the conveyor in case one became plugged or inoperable.

Control interlocks were provided to trip individual augers or the entire feed system in the event of material flow stoppages within the system.

Standard design Riley pneumatic air-swept distributor spouts fed fuel into the furnace where the RDF was combusted both in suspension and on the stoker grate. The refuse distributors were retrofitted onto the unit for the tests, as was an auxiliary air system to supply fuel-transport air and combustion air. A detailed discussion of the considerations in RDF feeding and combustion is provided in Section 5 of this report.

The Battelle system had a peak feeding capacity of approximately 14 tph and was operated at a maximum average rate of 6.4 tph over an eight-hour period. Over the duration of testing (9 weeks), the throughput generally ranged from 1 to 3 tph.

Operation of the system was reported to be generally good with few problems. An early plugging problem with long pieces of rags at the conveyor/auger transfer hopper was corrected with the addition of a roller to prevent buildings in the hopper. Further information on the system and related combustion testing are available from the report submitted to EPA by Battelle (Ref. 1).

Total cost for the fuel receiving, metering, and transport system (to the interface of the gravity feed chutes) was $154,000 in 1977. This figure includes $15,000 for design; $138,000 for fabrication and installation of the equipment (includes $25,000 for the trailer-mounted push pit and $15,000 for the belt conveyor); and $1,000 for miscellaneous expenses. A more detailed cost evaluation will be provided later in this section.

Canada Cement System. The Ontario Ministry of Environment, Resource Recovery Branch, conducted several tests in July and November 1979 at the Canada Cement Plant in Woodstock to determine the feasibility of utilizing RDF as a supplementary fuel in a rotary cement kiln (Ref. 2). Fifty-cubic-foot bales of RDF weighing approximately 950 lb each (19 pcf) were delivered to the plant by truck from the Ontario Centre for Resource Recovery in Toronto. The RDF produced at the resource-recovery facility contained approximately 16 percent moisture and had a maximum 6-in. size (90% <1 in.).

Bales were unloaded by forklift onto a receiving platform, where the bale wires were cut and removed. A 48-in.-wide belt conveyor transported the bales into a hopper containing a series of rotating spike rollers. The rollers acted to break up the bales and the material then dropped into a hydraulically driven, counter-rotating shear shredder unit. The hydraulic drives made it possible to vary the discharge rate and to reverse direction if plugging occurred. Agglomerations were broken apart and minus 2-in.-shredded RDF discharged onto a 48-in.-wide, 15-ft-long weigh-belt conveyor. This "weightometer" unit has a temperature-compensated strain gauge load cell and generated a signal that varied the discharge rate of the shredder according to feedrate requirements to the kiln.

Material from the weigh conveyor was discharged into a rotary air-lock feeder and then pneumatically conveyed 400 ft into the kiln. Figure 10 illustrates the system and equipment (designed by Kilborn Engineering).

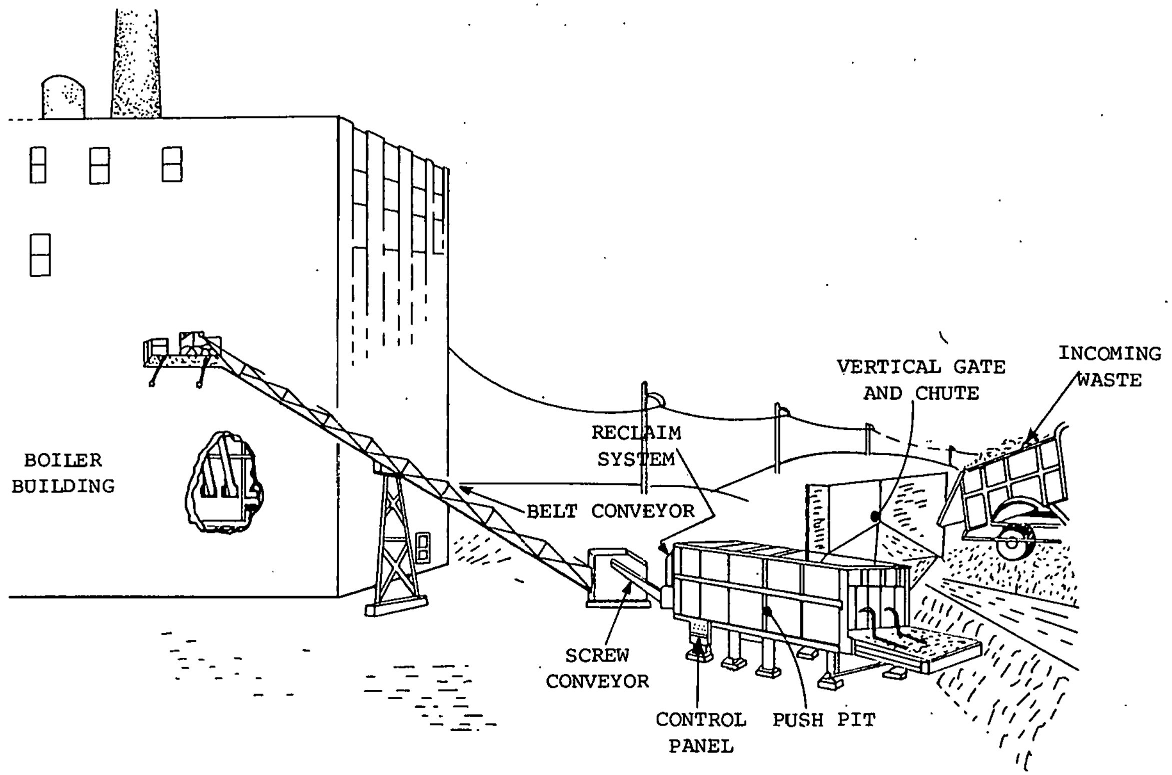

Figure 7. Sketch of Battelle Refuse Receiving and Feed System at Columbus Municipal Electric Co.

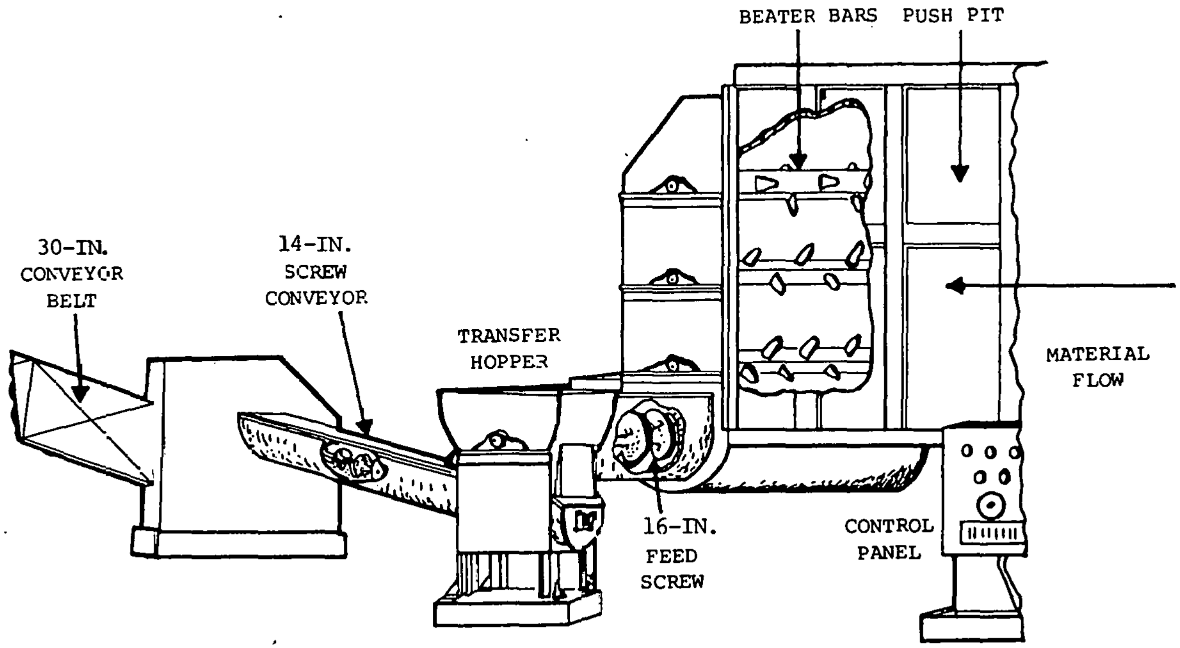

Figure 8. Sketch of the Battelle Refuse Reclaim System

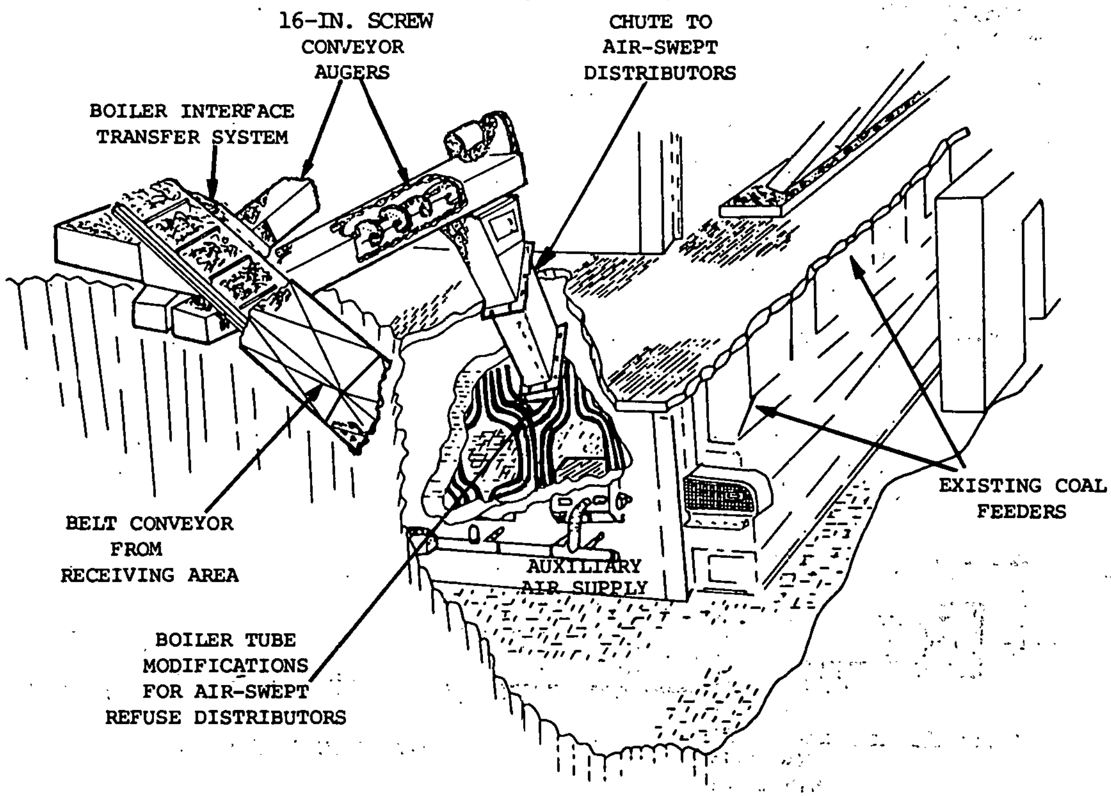

Figure 9. Sketch of the Battelle Furnace Refuse Fuel Feed System

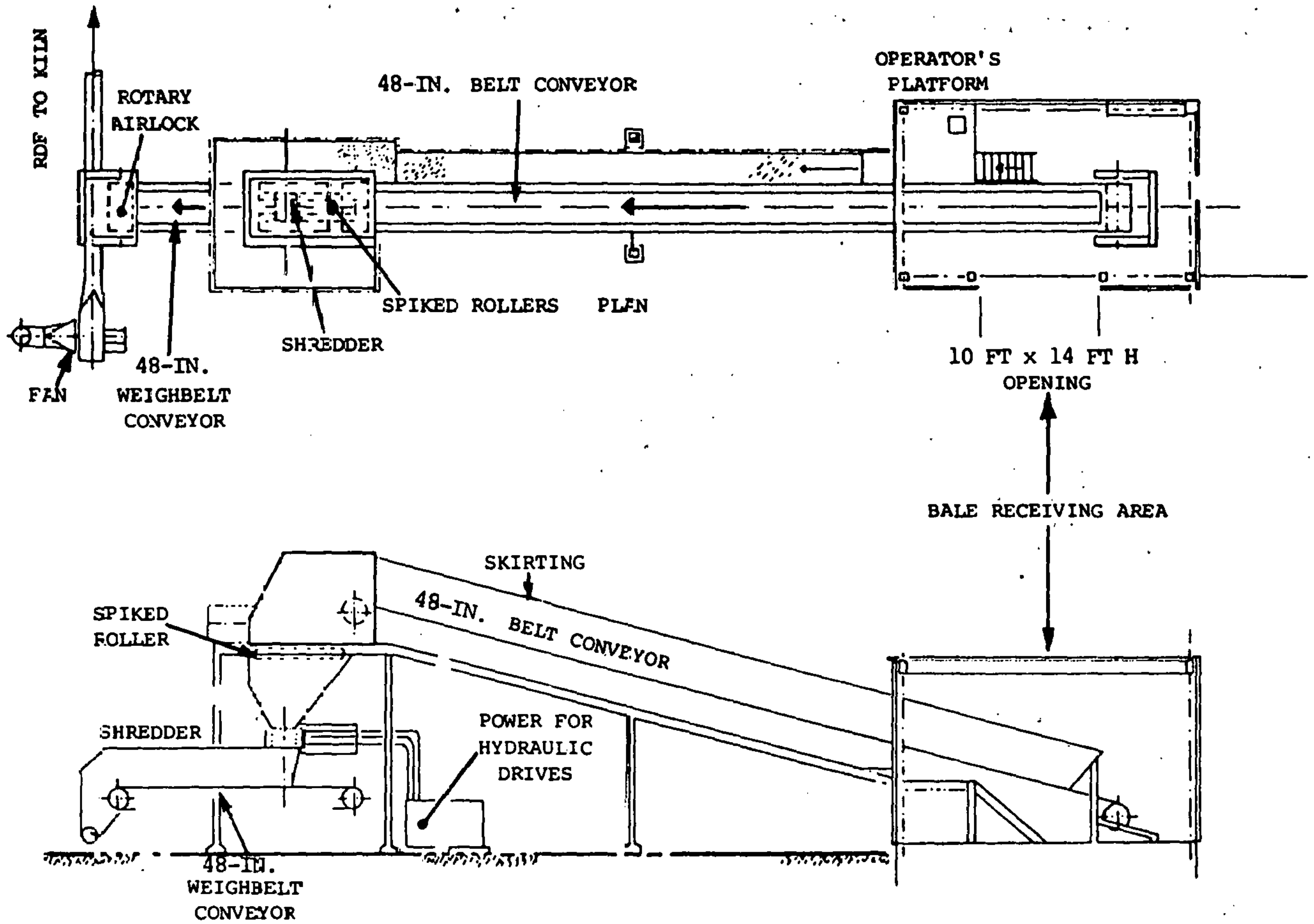

Figure 10. Sketch of Baled RDF Receiving and Kiln Feed System at Canada Cement

The system was rated at approximately 7 tph (maximum), although generally limited to 4 tph during operation. Plant operating personnel indicated that the spiked rollers and shredder system proved to be the limiting factor in achieving feedrates greater than 4 tph. They recommended utilizing a high-speed hammermill or flail rather than the relatively slow-speed shear shredder. For simplicity and ease of maintenance, electric drives were recommended over the hydraulic drives.

The bale-unloading-and-conveying systems worked quite well, as did the weigh belt conveyor. If necessary for the mobilizable project, it would be possible to replace the pneumatic transport system to the boiler with a mechanical conveyor system. This would eliminate the need for a blower and fan system as well as for an air/solid separator (cyclone).

Total reported cost for the entire system was $295,000 in 1977. This included design and engineering, installation, and modifications. The cost to make such a system transportable may be considerably less since the system would be reduced in physical size and complexity. Savings could be realized primarily in installation ($133,000) and engineering ($46,000) costs. Replacing the hydraulic drives on the shredder ($16,000) with electric drives could save $10,000. A more realistic figure for a mobile system might be $200,000 to $225,000, and a more detailed cost evaluation will be presented later in this section.

Heil Co. System. In 1976, the Heil Co., Milwaukee, Wisconsin, designed and assembled a solid waste shredding and combustion feeder facility for installation in Prudhoe Bay, Alaska. The equipment was built in Milwaukee and shipped by truck to the site, where truck wheels and axles were removed and the equipment installed permanently in place. The waste storage/metering equipment is of particular interest for this program.

Incoming solid waste is dumped from trucks onto a pan conveyor system that feeds a mobile Heil shredder. Ferrous metals are removed with an overhead magnet, and the waste is then conveyed into one of three modified transfer trailers. The trailers serve as both a storage and a metering and feed system. A hydraulic ram forces material in a steady flow (approximately 3 to 5 tph) from the trailer onto a variable-speed transverse-pan conveyor at the end of the trailer. Material is discharged from the transverse conveyor onto a second conveyor, and is then directed into a feed chute. A continuous cycle hydraulic ram then forces the material, under pressure, several yards through a circular pipe into a combustion unit for burning.

The system is of interest since it was designed and built to be transportable and to store and meter shredded solid waste and since it has been operated longer than any other system evaluated.

Teledyne National System. Teledyne National Corp., which operates the Baltimore County Resource Recovery Facility, designed and built a portable system to receive, meter, and feed RDF for combustion testing. The equipment was used intermittently for testing at a cement kiln in Union Bridge, Maryland, from 1977 to 1979 and for testing at a coal-fired utility boiler owned by Baltimore Gas & Electric Co. in July 1980.

Transfer trailers deliver RDF to the test site and into a portable receiving system. Two trailers can simultaneously unload material onto separate variable-speed pan conveyors, which in turn feed a common transverse pan conveyor. The transverse conveyor discharges RDF into a rotary air-lock feeder and pneumatic transport system to the boiler.

The system, which has operated at as high a load as 10 tph, is simple in design and operation. The pneumatic transport system could be replaced by a mechanical conveyor if necessary. However, the system is designed to handle loose RDF delivered by transfer trailer only; modifications would be required to accommodate baled fuels.

Fuel-Production and Feed System Costs

Capital and contingency costs for the RDF and d-RDF mobile production systems and for two representative feed systems, Battelle and Canada Cement, are developed in this section. The figures are based on 1981 dollars, and appropriate contingency factors have been applied as noted.

The cost of individual equipment items for the production systems, based on quotations provided by equipment vendors for similar hardware, were modified to include certain items not normally provided by the suppliers, i.e., motor starters, controls, mounting structures.

Additional costs for design and engineering; procurement, assembly, and shakedown; spare parts; and freight, shipping, and fees were determined by multiplying the subtotal cost of equipment by appropriate percentage factors, as indicated. These factors are generally considered to be typical to economic evaluations of such systems. This second subtotal was then multiplied by a 10 to 20 percent contingency factor to provide for unknown or additional costs.

For each of the three production systems evaluated, the cost of a new mobile shredder was included. It should be assumed that the Heil shredder, currently the property of DOE, will not be available or that the cost of rehabilitating it would be excessive.

Both the Battelle and Canada Cement fuel feed systems were originally reported in 1977 dollars; they have therefore been escalated at 10 percent per year to reflect their estimated 1981 costs. Significant modifications that would simplify and reduce the size of a mobile system similar in design to the system at Canada Cement are also reflected in the lower 1981 cost estimate as compared to 1977.

The cost summaries, provided in Tables 13 through 17, are intended only to provide order of magnitude costs (1981) for the three RDF/d-RDF production systems and two metering systems described previously. In evaluating these tables, refer to the Equipment Design Specifications provided earlier in this section as well as to the Manufacturer's Specifications provided in Appendix C.

Table 13. RDF Production System Cost Estimate

(Reference Fig. 2 and Equipment Design Specification Nos. 1, 2, 3, 5 and 6)

Trommel screen		$ 140,000
Magnetic separator		$ 12,000
Shredder (with electric drive)		$ 280,000
Material conveyors Nos. 5, 6, and 11 (includes hoppers, chutes, electrical controls)		$ 25,000
500-kw electric generator[a]		$ 95,000
Four transport trailers		$ 50,000
	SUBTOTAL A	$ 602,000
Design and engineering (12% Subtotal A)		$ 72,000
Procurement, assembly and shakedown (30% Subtotal A)		$ 181,000
Spare parts (10% Subtotal A)		$ 60,000
Freight, shipping, taxes, and fees (15% Subtotal A)		$ 90,000
	SUBTOTAL B	$1,005,000
Contingencies (20% Subtotal B)		$ 201,000
	TOTAL COST	$1,206,000

[a]Total connected h.p. ≈ 235; assume 1.5 h.p.; 500-kw generator provides reserve for auxiliary equipment, lights, and surge capability.

Table 14. Baled RDF Production System Cost Estimate

(Reference Fig. 2 and Equipment Design Specification Nos. 1, 2, 3, 4, 5 and 6)

Trommel screen		$ 140,000
Magnetic separator		$ 12,000
Shredder (electric drive)		$ 280,000
Material conveyors Nos. 5, 6 and 11 (includes hoppers, chutes, electrical controls)		$ 25,000
RDF baler with roller conveyor		$ 31,000
500-kw electric generator[a]		$ 95,000
Five transport trailers		$ 62,000
	SUBTOTAL A	$ 645,000
Design and engineering (12% Subtotal A)		$ 77,000
Procurement, assembly, and shakedown (30% Subtotal A)		$ 193,500
Spare parts (10% Subtotal A)		$ 64,500
Freight, shipping, taxes, and fees (15% Subtotal A)		$ 97,000
	SUBTOTAL B	$1,077,000
Contingencies (20% Subtotal B)		$ 215,000
	TOTAL COST	$1,292,000

[a]Total connected h.p. ≈ 265; assume 1.5 h.p.; 500-kw generator provides reserve for auxiliary equipment, lights, and surge capability.

Table 15. Densified-RDF Production System Cost Estimate

(Reference Fig. 5 and Equipment Design Specification Nos. 1, 2, 3, 5, 6, 7 and 8)

Trommel screen		$ 140,000
Magnetic separator		$ 12,000
Shredder (electric drive)		$ 280,000
Material conveyors Nos. 5, 6, 11, 12, 13, and 14 (includes hoppers, chutes, electrical controls)		$ 43,000
Tramp metals separator[a]		$ 75,000
Densifier		$ 105,000
750-kw electric generator[b]		$ 165,000
Five transport trailers		$ 62,000
	SUBTOTAL A	$ 882,000
Design and engineering (12% Subtotal A)		$ 106,000
Procurement, assembly, and shakedown (30% Subtotal A)		$ 265,000
Spare parts (10% Subtotal A)		$ 88,000
Freight, shipping, taxes, and fees (15% Subtotal A)		$ 132,000
	SUBTOTAL B	$1,473,000
Contingencies (20% Subtotal B)		$ 295,000
	TOTAL COST	$1,768,000

[a]A specific price quote was not available for the tramp metal separator/detector. The indicated cost was estimated by NCRR.

[b]Total connected h.p. ≈ 485; assume 1.5 h.p.; 750-kw generator provides reserve for auxiliary equipment, lights, and surge capability.

Table 16. Fuel Feed System Cost Estimate for the Battelle/Columbus Municipal Electric Co.

(Reference Fig. 7, 8 and 9)

Design		$ 15,000
Equipment fabrication and installation[a]		$138,000
Miscellaneous costs		$ 1,000
	SUBTOTAL A (1977 cost basis)	$154,000
Escalation (1977-1981)[b]		$ 71,000
	SUBTOTAL B (1981 cost basis)	$225,000
Contingencies (10% Subtotal B)		$ 22,500
	TOTAL 1981 ESTIMATED COST	$247,500

[a]Includes motors and starters, feed control system and interlocks, foundation, and site work. For a mobile system, the cost of trailers and additional assembly costs, if any, should be offset by the avoided cost of foundation and site work. The cost of permanent system and a mobile system are therefore assumed to be equal.

[b]Assume escalation of 10 percent per year over a period of four years.

Table 17. Fuel Feed System Cost Estimate
Canada Cement LaFarge, Ltd.

(Reference Fig. 10)

Actual installed system cost in 1977		
Spike rollers		$ 5,000
Shear shredder with hydraulic drives		$ 57,000
Weighbelt metering system		$ 17,600
Pneumatic fuel transport system		$ 25,000
Control system		$ 6,000
Design and engineering (Kilborn Engineering)		$ 46,000
Installation (includes bale receiving and conveyor system)		$133,000
	TOTAL INSTALLED COST (1977)	$290,000
Estimated cost of similar mobile system in 1981		
Spike rollers		$ 10,000
Shear shredder with electric drives		$ 31,000
Weighbelt metering system		$ 26,000
30-inch wide belt conveyor fuel transport system (100 ft)		$ 23,000
Controls		$ 5,000
Two transport trailers		$ 20,000
	SUBTOTAL A	$115,000
Design and engineering		$ 20,000
Equipment fabrication, assembly, and shakedown		$ 70,000
	SUBTOTAL B	$205,000
Contingencies (10% Subtotal B)		$ 20,000
	TOTAL 1981 ESTIMATED COST FOR MOBILE SYSTEM	$225,000

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1. Vaughan, D. A., H. H. Krause, P. W. Cover, R. W. Sexton, and W. K. Boyd, "Summary Report on Environmental Effects of Utilizing Solid Waste as a Supplementary Power Plant Fuel," Industrial Environmental Research Laboratory, U.S.E.P.A., Research Grant No. R804008-02-2, Battelle Columbus Laboratories, Columbus, Ohio, September 1978.

2. Luka, R., "Burning Refuse-Derived Fuel - The Woodstock Experience," presented at the Seminar - Energy from Waste in Canada, Toronto, Ontario, November 21, 1979.

SECTION 5

RDF COMBUSTION EVALUATION

Introduction

In most instances, the industrial-sized boilers most likely to be selected for testing as part of the Mobilizable Program will be existing units designed to burn stoker coal or wood wastes as their primary fuel. It will, therefore, be necessary to modify these units somewhat to accommodate the firing of RDF or d-RDF as a supplemental fuel. Each unit must first be evaluated as to its design and performance characteristics to determine its acceptability for cofiring refuse fuels. If, as a result of the evaluation, extensive modifications are deemed necessary to ensure a successful test burn, alternate boilers requiring a minimum of changes should be considered.

This section, which provides background information on the various unit design, performance, and operational characteristics necessary for proper combustion of RDF, is intended to serve as a guide for preliminary unit evaluations to determine a unit's acceptability for cofiring RDF as a supplementary boiler fuel with coal or wood waste.

Included are discussions on the limitations of RDF utilization in units not originally intended to burn RDF; boiler design considerations that determine a unit's suitability for RDF burning; approaches and hardware utilized to feed both RDF and d-RDF into the furnace; detailed evaluations of three representative, industrial-sized units to determine their relative acceptability for RDF burning; descriptions of the major modifications likely to be needed for burning RDF and associated costs; a detailed discussion on the potential for and mechanics of tube metal corrosion due to the chemical constituents in RDF; and a review of several systems and related equipment to receive, meter, and feed RDF to boilers.

It should be noted that most of the observations, conclusions, and recommendations provided in this section were developed in an engineering study and in subsequent discussions with Combustion Engineering, Inc., as well as in the review of existing literature as referenced throughout the text.

Limitations of RDF Utilization

Refuse-derived fuel is a nonhomogeneous fuel with properties that generally vary widely from sample to sample and from season to season. Its use as a supplemental fuel to replace a percentage of a primary fuel such as coal, bark, or wood chips (which are typically more homogeneous) in selected industrial-sized boilers has been successfully demonstrated and is being more and more frequently considered. Table 3 illustrated some of the properties of stoker coal and wood waste as well as of RDF and d-RDF. While good fuel preparation may reduce the variations in refuse, it is recommended that the percentage of heat input contributed by RDF be limited to roughly 20 percent for the following reasons.

To Minimize Fluctuations in Steam Production. This is due to the physical and chemical variations inherent in RDF, i.e., ash, moisture content, density, heating value. These variations affect the uniformity of the combustion rate and, therefore, steam flow. As a result, the responsiveness of the unit (ability to quickly swing steam load) is reduced as RDF input is increased. The combustion control system usually cannot adjust rapidly enough to variations in heat input due to RDF combustion; this results in steam-flow fluctuations.

To Minimize Steam Temperature Variations. Due to the varying properties of RDF and its effects on combustion, its use must also be limited to minimize temperature and pressure swings (since steam temperature and pressure track one another).

To Minimize Excess Air. Greater quantities of excess air--air in addition to that theoretically required for combustion--are required when burning heterogeneous fuels such as RDF as compared to more homogeneous fuels such as coal or wood waste. This is due to variations in the fuel and is intended to ensure more complete combustion and to prevent possible reducing atmospheres (a condition where insufficient combustion air is available) that promote metal corrosion. Bark- and coal-fired stokers are designed for approximately 30 percent excess air, pulverized-coal-fired stokers for 10 to 20 percent, and waste-fuel fired stokers for 40 to 50 percent. The potential for steam-tube erosion increases with higher excess air due to increased gas velocities and particulate carryover. Since most combustion air fans are sized with a tolerance of plus or minus 20 percent under ideal conditions, little if any excess fan capacity may be available to accommodate the higher air flows necessary for firing waste fuels in existing boilers. Restrictions on induced draft (ID) fans are particularly pronounced. The volume of air through the ID fans increases due to heavier flue gases resulting from the use of high moisture content refuse fuels.

To Limit Loading on Air Pollution Control (APC) Equipment. Generally, for each one percent increase of RDF usage by heat input, a corresponding one percent increase in flyash loading is predicted. For instance, the combustion of 10 percent RDF by heat input with coal will result in an increased flyash loading of 10 percent at the inlet to the APC system. The increased volume and velocity of air required for RDF combustion will reduce the efficiency of the APC equipment. The combustion of any solid fuel in a stoker system, particularly RDF, will result in higher amounts of unburned carbon particles reporting as flyash when compared to suspension burning systems. Stokers generally achieve less complete burnout of combustible material on the grate and thus generate more unburned carbon in the form of flyash. This carbon tends to decrease the resistivity of the flue gases and, therefore, also decreases the efficiency of an electrostatic precipitator in removing particulate matter. The increased carbon loading can also result in greater fire potential in ash hoppers and baghouse equipment.

To Prevent Damage to the Superheater. The burning rate of RDF in a unit equipped with a high temperature superheater must be limited to minimize the damaging effects of tube-metal corrosion. As a general rule, when firing RDF, superheater tube metal temperatures should be limited to 850°F (corresponding to 750°F superheated steam) to avoid high-temperature corrosion problems (Fig. 11). The higher the required final superheater outlet temperature for a particular unit, the lower the recommended allowable heat input from RDF. In units firing less than 20 percent RDF by heat input with coal, superheater tube metal temperatures may be allowed to go slightly higher than 850°F without developing excessive corrosion. As a potential but unquantified benefit of firing RDF with coal, the chemical properties of coal ash tend to have a neutralizing effect on the corrosion potential of RDF ash (Ref. 1).

Boiler Design Considerations when Burning RDF

Satisfactory burning of refuse-derived fuels in combination with coal or wood wastes requires that certain design parameters related to the combustion unit be met. Unless these criteria are met--be they designed into the unit or added as later modifications--operational and maintenance difficulties will probably arise and serve to discourage continued use of RDF as a supplemental fuel source.

The following design areas should be considered when evaluating the suitability of a unit to successfully firc RDF.

Fuel Firing System. The majority of coal- or wood-burning (primary fuel) combustion units in the 100,000 to 150,000 lb/hr range are semi-suspension-fired spreader-stoker boilers (Fig. 12). This firing system is ideally suited to a variety of waste fuels that have a high moisture content and a large particle-size distribution, and especially to a fuel as heterogeneous in nature as RDF. They are designed to feed fuel onto a grate within the furnace and to remove the ash residue. Mechanical or pneumatic distributors feed fuel into the furnace and distribute it across the stoker or burning grate. The lighter fuel fraction burns in suspension above the grate. Heavier materials not entrained in the upward moving furnace gases will fall to the grate surface, where final combustion will take place. Such semi-suspension burning, combined with controlled fuel metering, will produce fast boiler response to maintain stable operation when the fuel or steam demand changes quickly (Ref. 1).

For RDF firing, a continuous-ash-discharge stoker, commonly referred to as a traveling-grate stoker, is preferable to a stationary dump-type grate stoker. The continuous-ash-discharge stoker moves from the rear to the front (feed end) in the

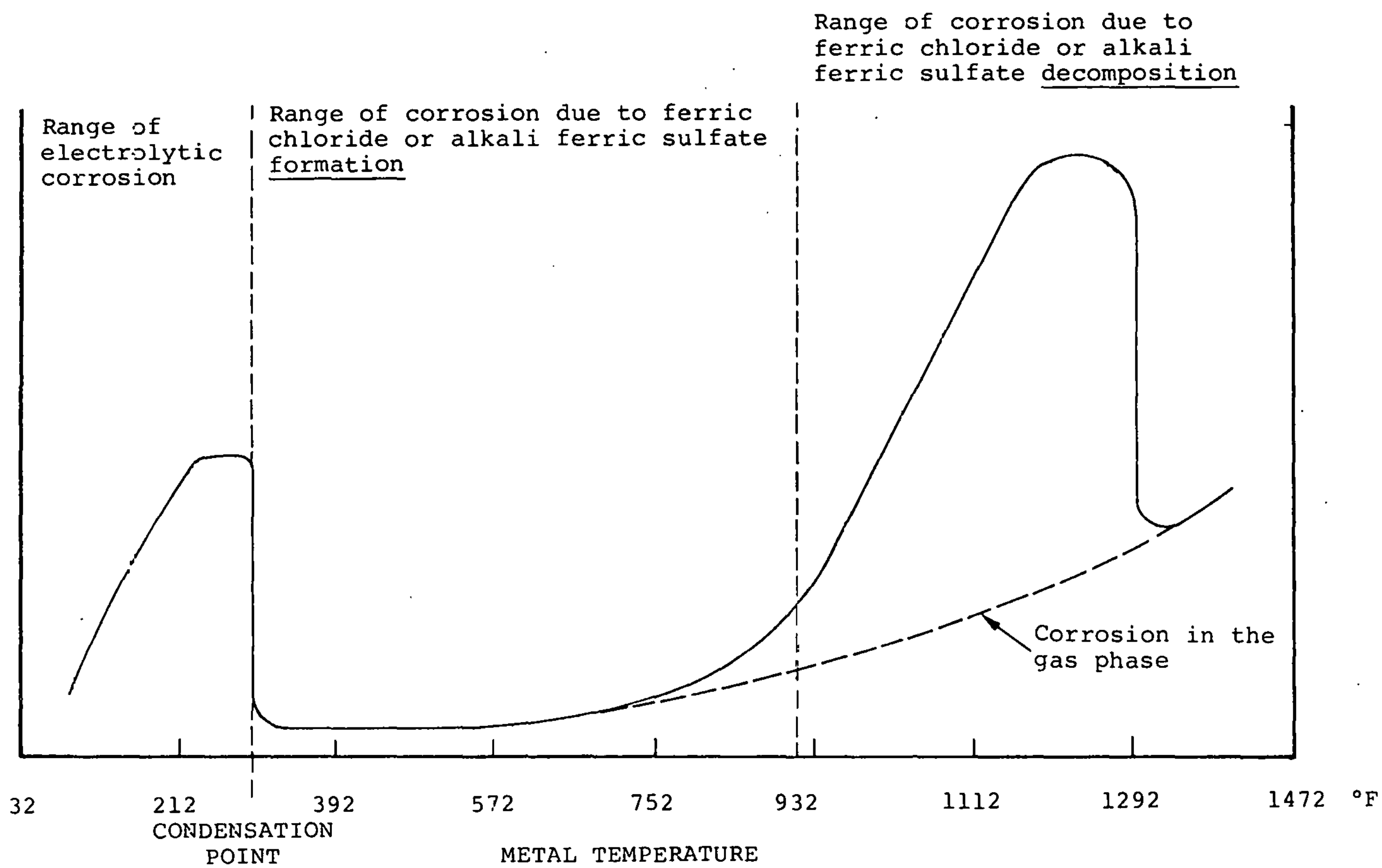

Figure 11. Relative Rate of Corrosion as a Function of Tube Wall Metal Temperature. Source: Reference 1.

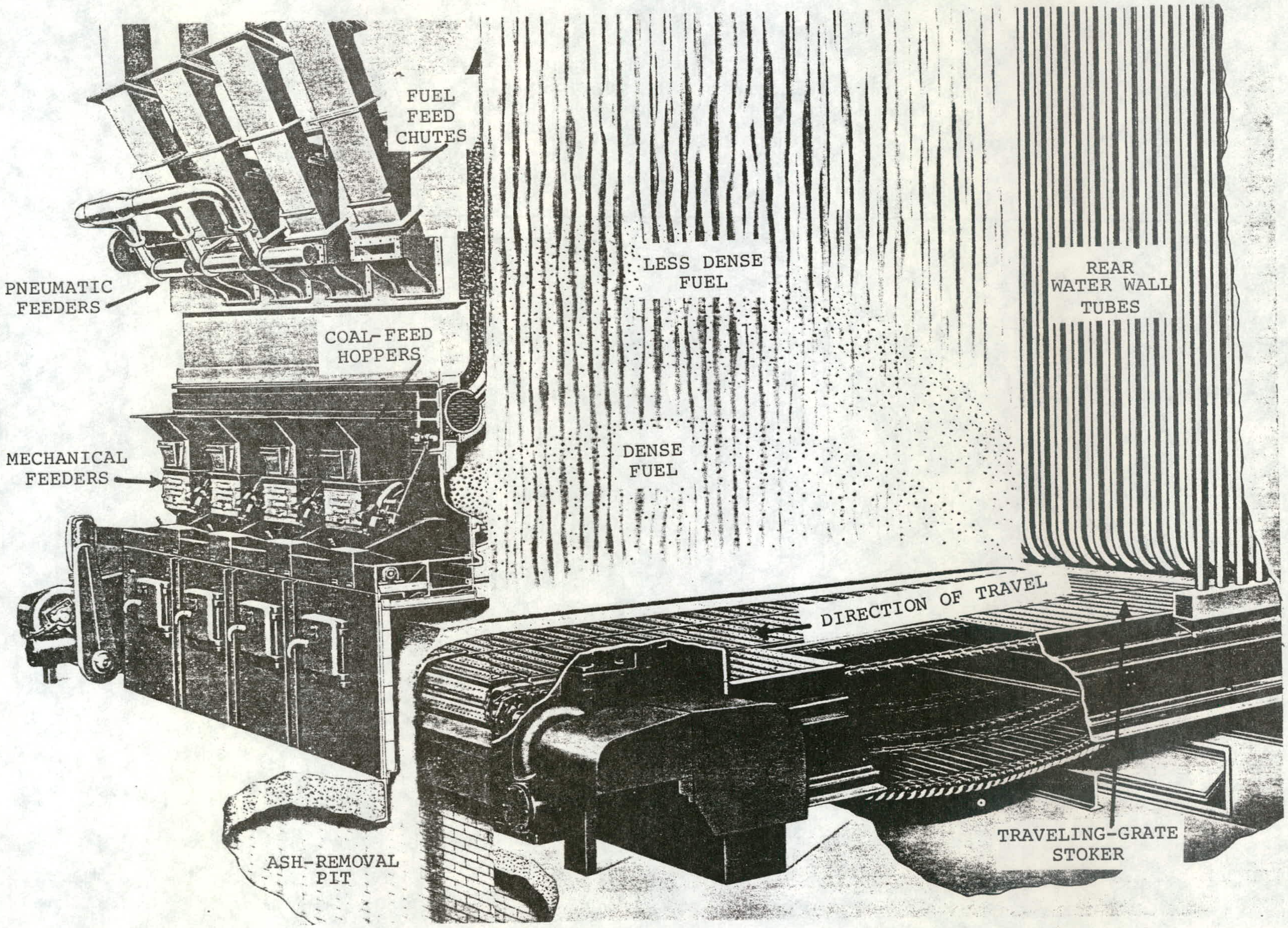

Figure 12. Typical Spreader Stoker Boiler Arrangement
Source: Detroit Stoker Co.

furnace, with the feeders designed so most of the fuel is distributed across the rear one third (Fig. 13). A greater volume of underfire air is, therefore, required in this area to ensure complete combustion. With the continuous-ask stoker, underfire air to the grate can be zoned through undergrate air compartments isolated by a series of drag seals. This allows the boiler operator to bias air flow toward the rear as required, and permits optimized stoker operation to compensate for varying air requirements as the characteristics of the fuel change and the ash bed moves through the furnace.

With a dump-grate system, no such zoning or biasing of undergrate air is possible (Fig. 14). The operator can only adjust the fuel distributor feed pattern in the furnace. This system is much less sensitive to variations in fuel properties and flow. However, its capital cost and operations and maintenance costs tend to be lower than those for the continuous-ash system.

The grate-heat release rate for a particular stoker type and fuel is the determining factor in sizing grate area for a specified boiler size (rated steam flow). The heat release rate is a function of the fuel burned relating to moisture and ash content as well as to volatility. Dense, low-moisture, low-ash, highly volatile fuels such as stoker coal can cause grate overheating if fired in large quantities. The stoker is normally kept below design temperatures by maintaining a layer of protective ash on the grate surface and supplying underfire air below 350°F (Ref. 2). The maximum great heat release rate firing stoker coal ranges from 450,000 Btu/hr per ft^2 on a dump grate to 750,000 Btu/hr per ft^2 on a traveling-grate spreader stoker. Due to their higher moisture and ash contents, waste fuels such as bark and RDF can have much higher grate heat release rates--up to 1,000,000 Btu/hr per ft^2.

Furnace Volume. Proper furnace sizing, as well as arrangement of heating surfaces and correct positioning and use of sootblowers, can help optimize unit efficiency and reduce boiler fouling from slag and flyash deposition. Proper furnace sizing implies adequate volume and retention time to ensure complete fuel combustion. Sufficient water circulation to reduce the temperature of the products of combustion to the point where the ash is not fluid and will not adhere to boiler tubes must also be supplied. Ash deposit is difficult to remove with sootblowers (Ref. 3).

Furnace sizing is expressed in units of Btu/hr per ft^3 of volume. Units designed to burn high-Btu, low-ash fuels such as oil and natural gas are referred to as having high heat release rate furnaces and are, therefore, relatively small and compact. Units designed to burn lower-Btu, higher-ash solid fuels such as coal or refuse have low heat release rate furnaces that tend to be much larger in volume.

Some typical heat release rates for various boiler fuels are as follows:

oil and gas	>50,000 Btu/hr per ft^3
pulverized coal	15,000-20,000 Btu/hr per ft^3
stoker coal	25,000-30,000 Btu/hr per ft^3
stoker bark	25,000-30,000 Btu/hr per ft^3
RDF (stoker)	15,000-20,000 Btu/hr per ft^3

Using a stoker system to burn coal results in a large percentage of the fuel burning on the grate. A stoker boiler is designed for a higher heat release rating and will have a smaller furnace than a unit burning pulverized coal in suspension, thus for a given fuel flow. Consistent with this, since a higher proportion of RDF burns in suspension than does coal or bark in a stoker system, the furnace heat release rate for RDF will be lower and the furnace size greater. This suggests that limited furnace volume may be a problem when burning RDF in a boiler designed for coal or bark.

Overfire Air System. Overfire air is utilized as an aid in drying and burning suspended particles of fuel and the volatiles released from the fuel bed on the grate. This air mixes with the furnace gases and creates the turbulence required to complete combustion. The result of insufficient overfire air is the generation of additional quantities of flyash, unburned carbon, and carbon monoxide (CO). The proportion of overfire air to total air varies, depending on the fuel type and the amount burning in suspension. As a rule, the amount of overfire air as a percentage of total unit air flow required for refuse fuels is approximately 40 to 50 percent; for the stoker coals it is 20 to 25 percent; and for bark, 30 to 50 percent.

Generally, either low-pressure or high-pressure air is employed. Low-pressure air, typically 8 in. W.C. and drawn from preheated, forced-draft fan air, is utilized for RDF and bark burning where more combustion air and greater turbulence are needed above the

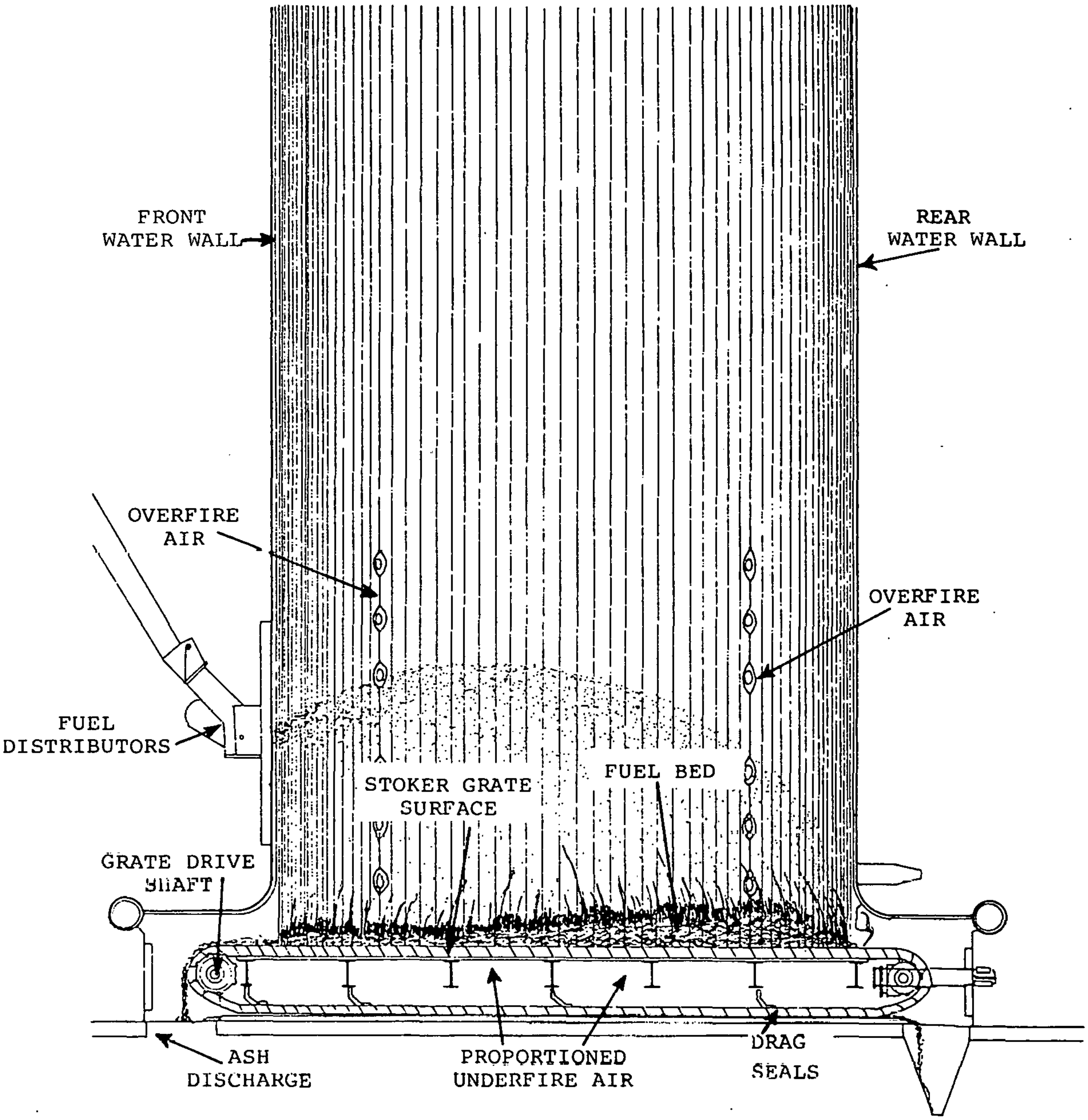

Figure 13. Arrangement of Continuous Ash Discharge Stoker. Source: Combustion Engineering, Inc.

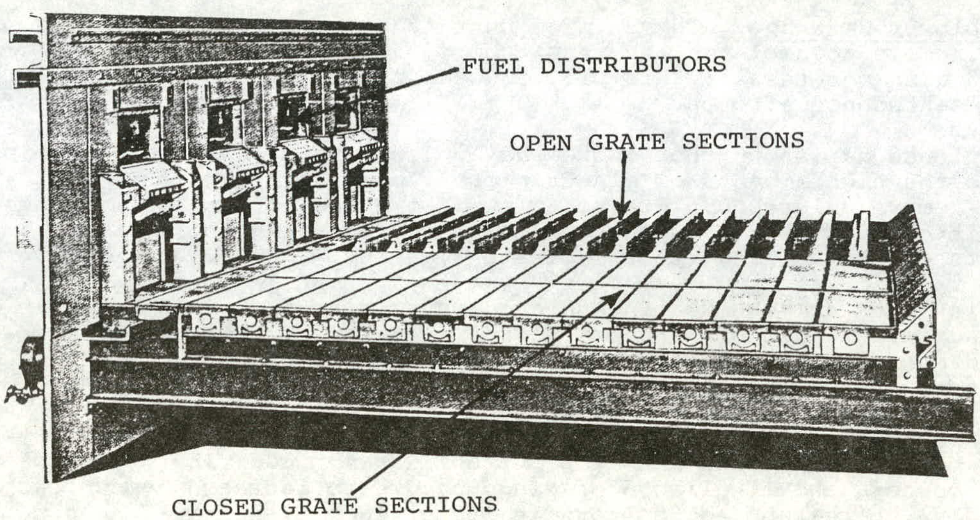

Figure 14. Arrangement of Intermittent Dumping-Grate Stoker.
Source: Detroit Stoker Company.

stoker grate. High-pressure overfire air, typically 30 in. W.C. and generated by a separate fan, is used primarily for stoker coal to direct and force combustion air into the top of the fuel bed.

When modifying a boiler to fire RDF, overfire air can be added in part through the fuel distributors or injected from above the feeders. The air should not be introduced below the feeder since this could inhibit proper fuel distribution over the grate surface

Furnace Configuration. Refuse-derived fuels, which contain a relatively high content of ash, tend to be quite abrasive. It is important, therefore, to minimize as much as possible the number of turns in the convective zones of the boiler through which ash-laden flue gases flow. This will minimize turbulence and limit high localized velocities associated with tube erosion and wastage. The recommended maximum design flue-gas velocity in the convective zones of units burning refuse fuels is approximately 30 ft.

Units designed with single-pass boiler banks to minimize erosion problems are preferable to those with multiple baffled passes. Most new, solid-fuel-fired boilers utilize multiple passes, making them less suitable for burning RDF (Fig. 15).

Tube Spacing. The superheater and convective surface tubes should be so spaced that they allow for some ash buildup without bridging from tube to tube. In-line (as opposed to staggered), widely spaced tube arrangements are recommended to minimize plugging and to ensure the accessibility of tube surfaces for cleaning.

Sootblower Coverage. To maximize heat transfer and efficiency, sootblowers are required to remove accumulated ash from tube surfaces. Unless adequate coverage is provided, severe plugging can result; this will reduce unit efficiency and steam temperatures and increase maintenance efforts.

Experience has shown that increased fouling and slagging can be expected when firing RDF due to the high amounts of glass in the fuel. The slag is generally molten and difficult to remove unless complete sootblower coverage is available. Additional blowers can be retrofitted on a unit by simply splicing off existing steam or air lines. Retractable sootblowers can be utilized to facilitate cleaning.

A thin layer of accumulated ash can serve to protect tube surfaces and extend tube life. Discriminate sootblowing procedures (generally required when steam temperatures begin to drop) will reduce the exposure of cleaned tube surfaces and make the metal less vulnerable to attack from flyash erosion and chemical corrosion.

Heat Recovery Equipment. Several factors regarding heat recovery equipment must be addressed before evaluating a unit's suitability for cofiring RDF. These factors generally concern the likelihood of plugging due to increased amounts of flyash. The use of continuous, bare-tube economizers is preferred over spiral-fin economizers, although the former are less efficient. Spiral-fin tubes plug more readily with high-ash fuels such as RDF and are difficult to clean.

If an air preheater is included on the unit, a tubular system is preferable to the familiar Ljungstrom system. The Ljungstrom has closely packed heat transfer surfaces that are difficult to clean and that tend to plug easily on high-ash fuels such as RDF. The tubular system provides for a more direct flow of flue gases and air with fewer obstructions and is, therefore, much less likely to plug.

Methods for Firing RDF and d-RDF

Refuse fuels can be successfully burned in combination with coal and wood waste in industrial-sized boilers. Careful attention must be paid, however, to ensuring proper feed and distribution into the furnace to avoid steam-flow and temperature fluctuations and associated operational problems. A variety of feeders are available for introducing solid fuels into stoker boilers. The selection of a fuel distributor for a particular unit is dependent on the unit's design configuration and primary fuel. The objective is to provide a continuous, well-distributed supply of fuel at a variable rate as required by the load demand. Fuel distributors for stoker boilers utilize either mechanical or pneumatic systems to feed fuel into the furnace.

Mechanical Distributors. Mechanical distributors are generally designed to feed high-density solid fuels such as stoker coal, wood chips, bark, and densified RDF. This feeder utilizes a motor-driven overthrow rotor assembly to propel material into the furnace combustion zone and to distribute the fuel evenly over the grate surface (Fig. 16).

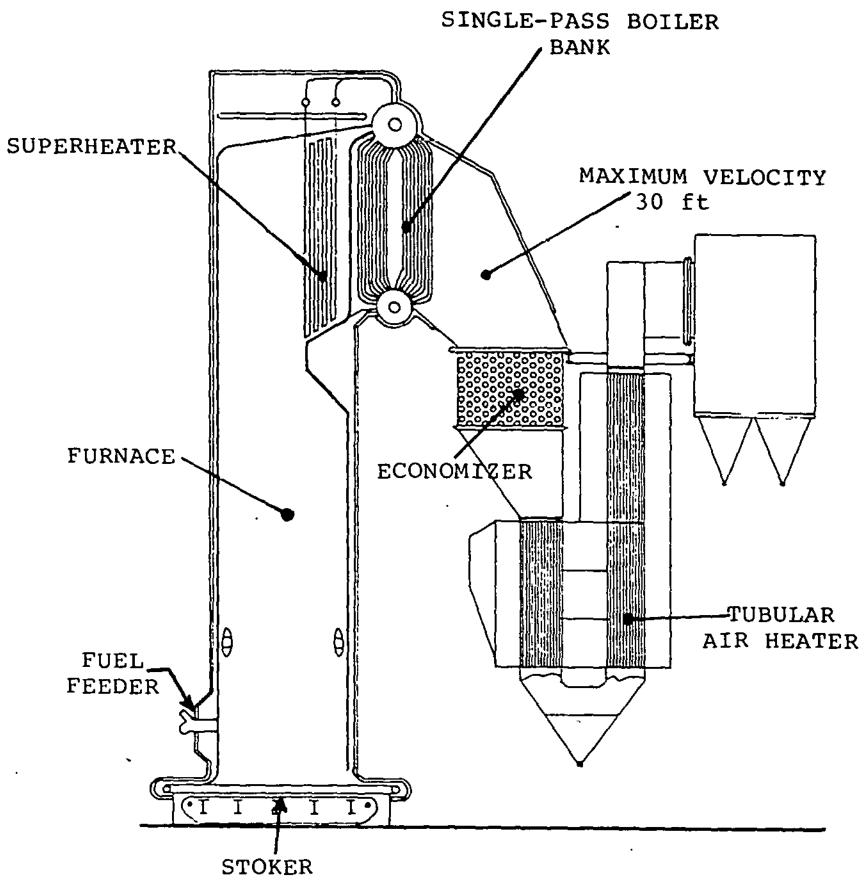

Figure 15. Arrangement of Typical Unit with Single-Pass Boiler Bank.
Source: Combustion Engineering, Inc.

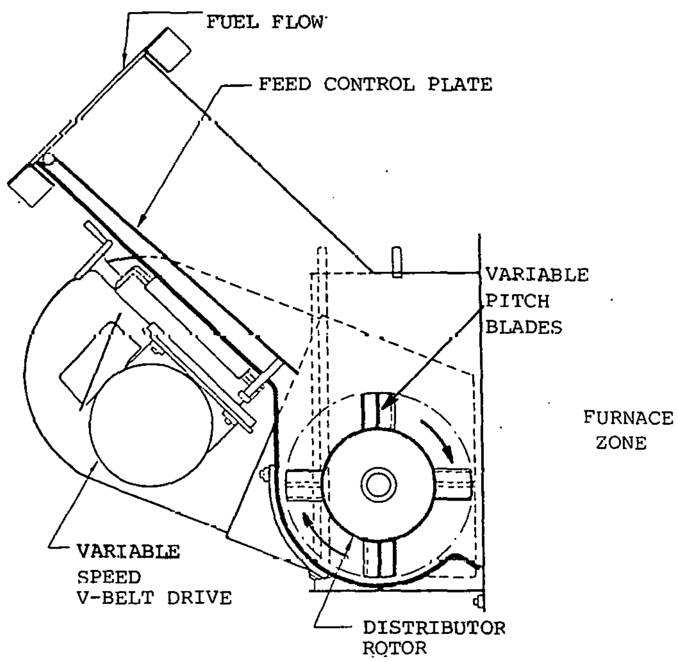

Figure 16. Mechanical Distributor:
Component Features.
Source: Combustion Engineering, Inc.

The rotor speed is adjustable and it may be equipped with either curved or straight blades to achieve uniform distribution. The larger, more dense particles are thrown to the back of the grate while lighter particles, particularly fines, will generally burn in suspension or drop to the front of the grate.

Mechanical distributors can be designed to feed either cellulose or coal fuels. The cellulose distributor has a higher velocity rotor and more severe blade angle than the coal distributor and is, therefore, better able to handle fuels such as bark or d-RDF that have a higher fines content. Combustion Engineering-designed feeders vary in width from 16 in. to 28 in. The cellulose distributors are designed to handle approximately 1200 pounds of fuel per hour per inch of width. The coal distributors are rated at 300 pounds per hour per inch of width.

Pneumatic Distributors. Pneumatic distributors, commonly referred to as air-swept distributors, are intended to feed low-density fuels that may contain a high level of fines. These include fluff RDF, bark, and bagasse. Fuel is gravity-fed to the distributor and blown or swept into the furnace by high-pressure transport air (Fig. 17). The trajectory of the fuel can be varied by adjusting the angle of both the air nozzle and a retention or deflection plate located at the feeder outlet. The transport air is supplied by a separate high pressure fan at a pressure of 30 in. W.C. and ambient temperature. The recommended quantity of transport air is 0.2 pounds of air per pound of fuel and accounts for roughly 5 percent of the total unit combustion air. In some feeder designs, a rotary damper at the air inlet header creates a pulsating flow that aids in evenly distributing fuel from front to rear on the grate.

Combustion Engineering pneumatic distributors vary in width from 20 in. to 28 in., and are rated at 100 pounds of fuel per hour per inch of width. Pneumatic distributors tend to be conservatively sized to ensure sufficient fuel capacity and proper distribution.

Feeder Positioning. The location of the fuel distributors (elevation above grate surface) will affect the combustion conditions and the final steam temperature and general operation of the boiler. Their location is generally a function of fuel density and level of fines.

The "low-set" position places a distributor approximately 3 to 4 ft above the grate surface and generally below front-wall pressure parts and headers. "High-set" distributors are located approximately 8 ft above the grate in bent-tube insert openings through front-wall pressure parts (Fig. 18). The result is longer trajectories, better fuel distribution, and more complete suspension drying and combustion. Both mechanical and pneumatic distributors, in either the low or high-set position, are spaced approximately 4 ft on centers.

High-density fuels such as stoker coal and d-RDF burn largely on the grate surface, have relatively low fines content, and should, therefore, be fed from the low-set position. Low-density fuels such as fluff RDF, however, burn largely in suspension and have relatively high fines content and should, therefore, be located in the high-set position in the furnace wall. The location of fuel distributors relative to the furnace outlet will affect retention time and combustion efficiency.

Feeding Methods for Retrofit Firing of RDF/d-RDF

RDF and Stoker Coal. The differences in fuel density and flow properties between fluff RDF and stoker coal precludes any mixing prior to feeding into the furnace. Separate feeders must therefore be utilized.

Coal is generally fed through mechanical distributors located in the furnace front wall in a low-set position; RDF feeding would be added through pneumatic distributors in a high-set position. Feeding these two dissimilar fuels through adjacent distributors (same elevation) is not recommended. It is important that all fuels be distributed evenly across the grate to avoid separate fuel lanes or rows. Such lanes would result in uneven temperatures across the width of the furnace due to varying combustion rates from the two fuels; performance problems due to poor distribution of heat and ash could develop. Low-pressure overfire air is recommended above the RDF feeders to ensure complete combustion.

RDF and Wood Wastes. Although fluff RDF and some types of wood waste have similar fuel properties, their physical properties will likely vary so that they cannot be handled as if they were identical.

In some applications, as with relatively dry, shredded bark, the two fuels can be blended together and fed into the furnace through existing pneumatic distributors.

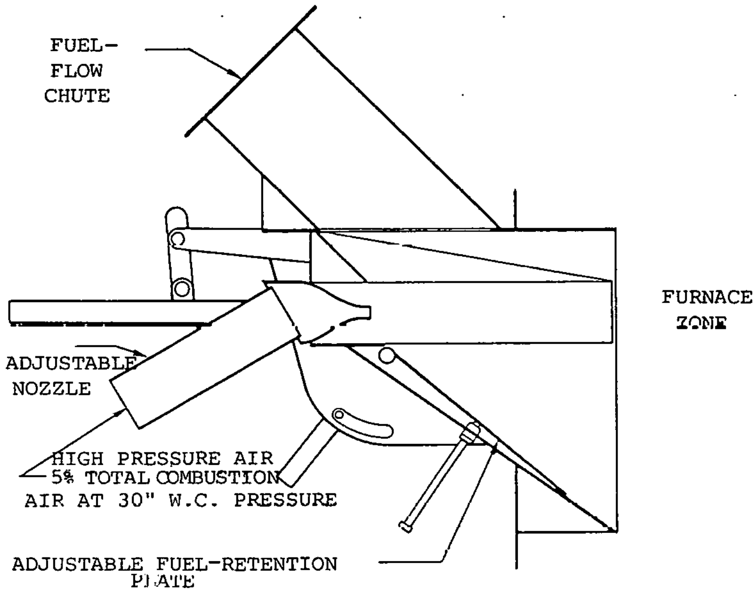

Figure 17. Pneumatic Distributor: Component Features. Source: Combustion Engineering, Inc.

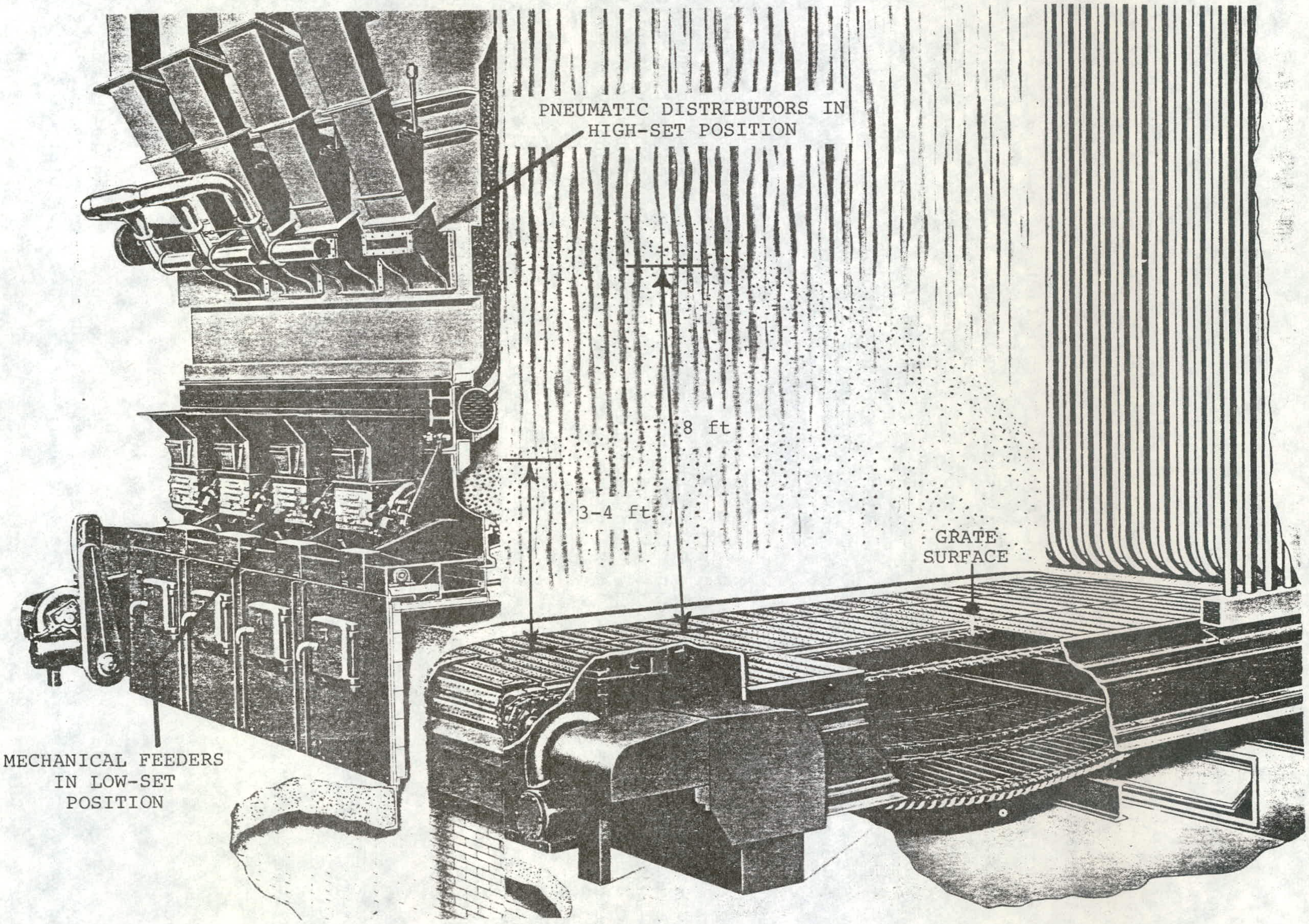

Figure 18. Location of Fuel Feeders.
Source: Detroit Stoker Co.

However, if the fuels cannot be blended or handled together easily, they must be fed through separate distributors. In this case, in order to maintain an even fire across the width of the grate, the two fuels should not be introduced through adjacent feeders, but rather from separate elevations.

Relatively dense wood chips, when combusted with RDF, should be fed through low-set mechanical cellulose distributors. As described previously, the RDF should be fed through high-set pneumatic distributors. The existing overfire-air system will probably have to be supplemented to provide sufficient turbulence and combustion air above the RDF feeders.

d-RDF and Stoker Coal. Due to the similarities between densified RDF and stoker coal (size and density), these fuels can be readily combined and fed into the furnace as a homogeneous mixture through existing mechanical distributors. Although past experience has shown that some fuel segregation is probable when d-RDF is blended with coal, blends with up to 66 percent d-RDF by weight have been test-fired with few serious feeding problems.

As an alternative, d-RDF can be fed through separate high-set mechanical cellulose distributors, while coal is fed from the low-set position. This is a viable alternative if mixing becomes difficult due to physical constraints at the boiler interface.

High-pressure overfire air should be provided for adequate combustion on the grate.

d-RDF and Wood Waste. Assuming the fuels are of like density, d-RDF and wood wastes can be fed in much the same way as stoker coal. However, if the wood waste is a low-density fuel, it may be necessary to feed d-RDF through mechanical cellulose distributors in the low-set position and wood waste through pneumatic distributors in the high-set position. Adequate overfire air is necessary to ensure complete fuel combustion.

Unit Evaluations

To more clearly illustrate the boiler design and equipment considerations developed previously, three representative, industrial-sized units will be described and evaluated in terms of their relative ability to burn RDF or d-RDF with coal or wood as the primary fuel. The three are Combustion Engineering-designed boilers designated as typical Model VU-10, VU-50, and VU-40 units. Units of similar design and performance characteristics are produced by the other major boiler manufacturers, and the three CE designs can be considered as being representative of those units in service around the country in this size range.

In this section, typical examples of the three boiler designs will be evaluated based on the design and performance considerations developed previously. On the basis of this evaluation, they will then be classified as being not recommended, marginal, or recommended for firing RDF as a supplemental fuel with coal or wood waste. In addition, the expected boiler performance and operating characteristics will be described for the VU-50 and VU-40 units, based on firing RDF or d-RDF with a HHV of 5500 to 6000 Btu/lb at full load.

VU-10 (Fig. 19)

steam flow	-	50,000 lb/hr (range 20 to 60,000 lb/hr)
steam temperature	-	saturated
primary fuel	-	stoker coal or bark
stoker type and size	-	dump grate, 15 ft wide x 12 ft long
fuel distribution system	-	mechanical distributors in low-set position
overfire air	-	none available

VU-10s are typically small, solid-fuel-fired boilers built in the 1940s and 1950s. Used primarily by institutions requiring relatively steady, continuous steam flow, they operate under lower pressures (less than 1800 psi) with natural circulation.

This type of unit is not recommended for firing refuse-derived fuel for the following reasons:

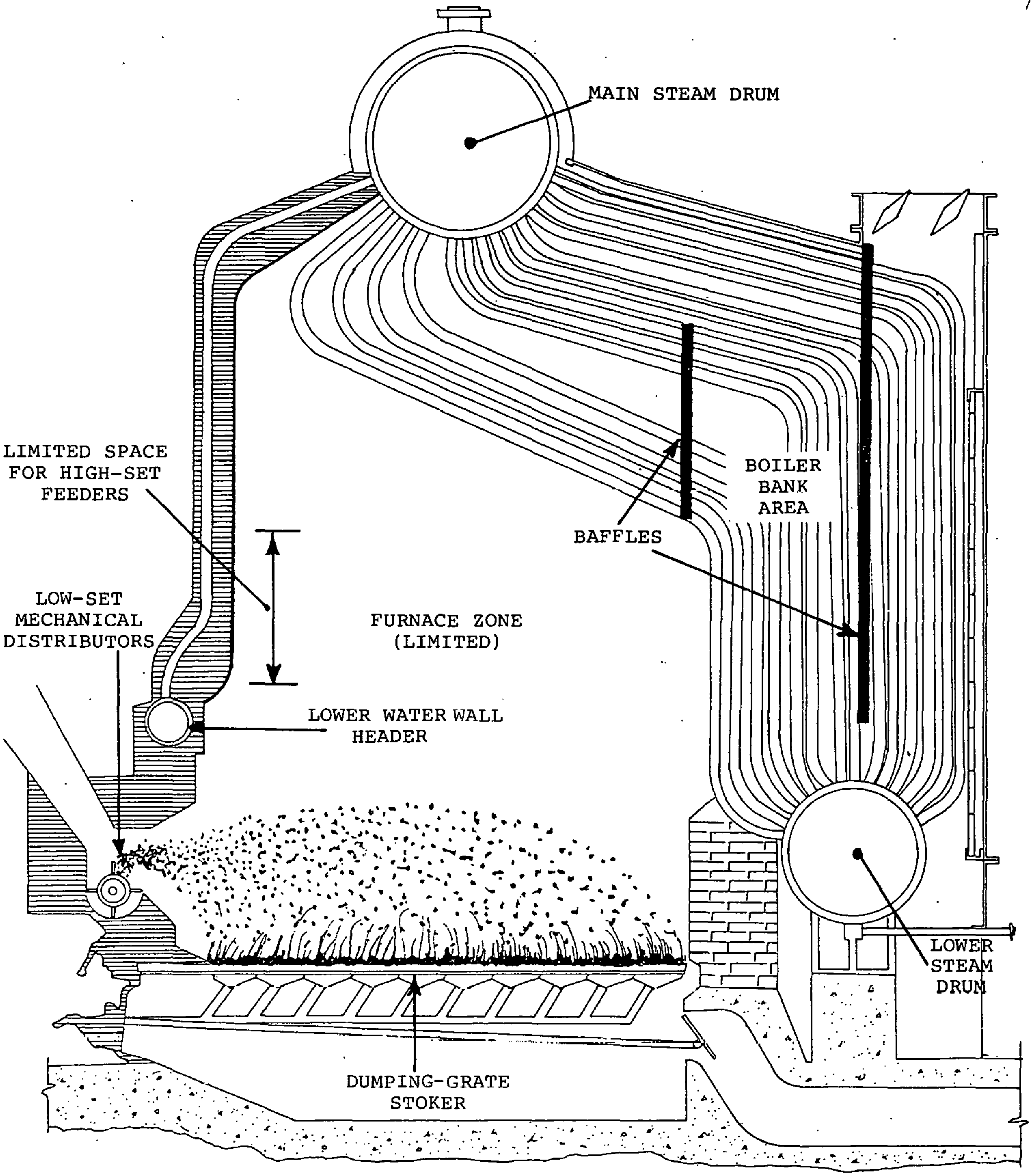

Figure 19. Arrangement of Typical VU-10 Unit.
Source: Combustion Engineering, Inc.

- the dump-grate stoker allows for only limited adjustment and distribution of underfire air and can, therefore, not compensate adequately for variations in fuel quality and quantity

- furnace volume is very limited and, therefore, inadequate for allowing sufficient retention time to ensure complete combustion of fuel

- the boiler configuration is such that sufficient space is not available to add a level of high-set fuel distributors and the required overfire air system, and structural impediments forbid installation of feeders directly above the existing mechanical distributors and below the water wall header

- the unit has a tight, baffled boiler bank that will result in high localized flue-gas velocities and increased erosion problems

- sootblower coverage is probably limited; thus, increased slagging and fouling of heating surfaces should be expected

<u>VU-50 (Fig. 20)</u>

steam flow	-	76,500 lb/hr (range 50 to 300,000 lb/hr)
steam temperature	-	725°F
steam pressure	-	565 psig
primary fuel	-	bark (also coal)
stoker type and size	-	dump grate, 13 ft wide x 12 ft long (continuous ash discharge also used)
fuel distribution system	-	three mechanical cellulose distributors in low-set position
overfire air	-	low pressure tangential, front and rear walls

The VU-50, essentially an outgrowth of the smaller, more limited VU-10 design, allows for more flexibility and a wider range of fuel utilization for industrial customers.

The unit illustrated in Figure 20 does have several limiting factors, and is, therefore, marginal for firing RDF for the following reasons:

- the dump-grate stoker allows only limited adjustment and distribution of underfire air and is, therefore, less preferred than a continuous-ash-discharge stoker. Many units of this design do utilize continuous-ash-discharge stoker systems, which makes them more suitable for burning RDF

- furnace volume is somewhat limited and may be inadequate to handle increased quantities of waste fuel

- the installation of a level of high-set fuel distributors could interefere with the operation of auxiliary oil burners normally located in the side walls, and limited furnace height does not allow sufficient retention time for all RDF particles to completely burn

- the boiler bank has several baffled areas, which will result in high turbulence with localized erosion problems and tube wastage

This unit does, however, possess several design features that contribute to the successful burning of RDF.

- the existing mechanical distributors can be readily utilized to feed a mixture of bark and d-RDF. Additional high-pressure overfire air would be required to ensure complete combustion on the grate

- to allow RDF firing, the existing mechanical distributors can be replaced with pneumatic distributors through which a mixture of bark and RDF can be fed

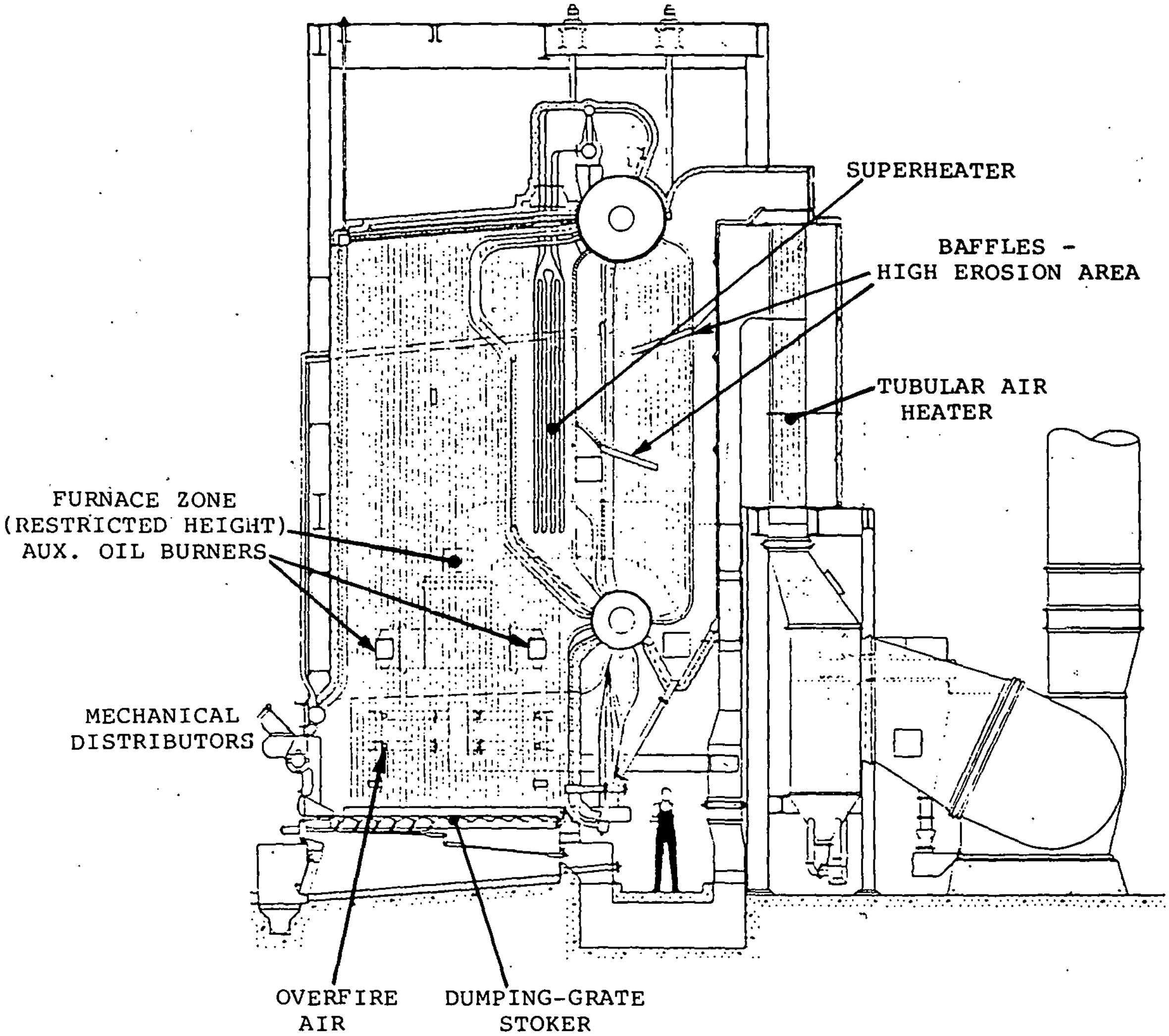

Figure 20. Arrangement of Typical VU-50 Unit
Source: Combustion Engineering, Inc.

- sootblower coverage in the superheater and boiler bank should be adequate since the unit is designed to burn waste fuels, in this case bark

- the tubular air preheater is the preferred system when burning RDF, and should prevent any plugging due to increased flyash loading.

When firing RDF in combination with bark, boiler performance should not be greatly affected due to similarities between the fuels, particularly when related to heating value. The following performance factors are noted:

- the maximum percent RDF utilization is highly dependent on the degree of furnace slagging and superheater and boiler-bank fouling as determined by actual operating experience. Based on the design and performance characteristics described earlier, it is anticipated that the maximum RDF input should not exceed 15 to 20 percent of the total unit heat input (actual boiler operation may indicate that a 20-to-25 percent level is possible)

- boiler efficiency in firing bark and RDF should remain roughly equal to that of bark only, 65 to 70 percent, and, depending on the actual moisture content of the RDF, a slight increase in boiler efficiency could occur with this fuel mixture since bark alone contains higher levels of moisture than does RDF

- additional quantities of excess air will be required to ensure complete combustion of RDF, although little excess ID fan capacity may be available to handle this added flow. The additional quantities of excess air necessary should be offset by reduced moisture levels in the flue gas as bark is replaced by RDF, therefore actual air and gas weights should remain roughly the same when burning the combined fuel

- the superheater outlet steam temperature and pressure should remain the same when burning bark and RDF (at the recommended rate of 15 to 20 percent RDF) as when firing bark only. At levels higher than this proportion, increased fouling and plugging of heat-transfer surfaces will ultimately reduce final steam temperature and pressure

- there is a direct relationship berween the RDF firing rate and total ash loading. Previous experience indicates higher than normal flyash loadings when burning RDF. As a general rule, a one-percent increase in flyash loading can be anticipated for each one-percent increase in RDF utilization. For example, when firing 20 percent RDF by total heat input, the flyash loading is expected to be approximately 20 percent higher. Increases in bottom ash would be anticipated with the generally higher ash content of RDF compared to wood or coal (assuming proper combustion and grate operation; this higher ash loading should present no additional problems).

VU-40 (Fig. 21)

steam flow	-	150,000 lb/hr (range 100 to 800,000 lb/hr)
steam temperature	-	750°F
steam pressure	-	640 psig
primary fuel	-	coal (bark secondary)
grate type and size	-	continuous ash discharge stoker, 17 ft wide x 20 ft long
fuel distribution system	-	three 28-in. mechanical cellulose distributors in high-set position and four 24-in. mechanical coal distributors in low-set position
overfire air	-	front and rear walls

The VU-40, an improvement over the older VU-50, essentially represents the current state-of-the-art in large, solid-fuel-fired industrial boilers. These units are designed to burn a variety of solid fuels, including waste, as a total or partial input fuel with a minimum of fuel preparation. This unit is, therefore, recommended for firing RDF as a supplement to coal or wood waste. Specific factors are as follows:

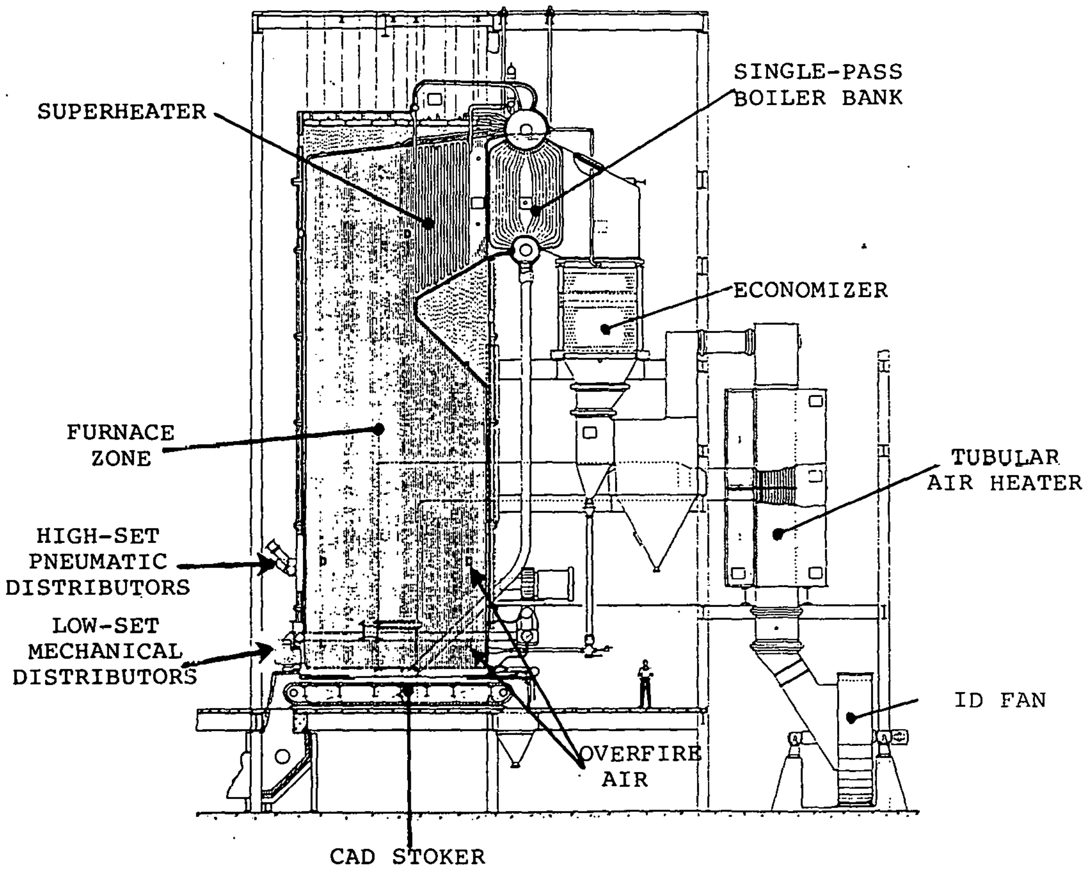

Figure 21. Arrangement of Typical VU-40 Unit.
Source: Combustion Engineering, Inc.

- the unit is equipped with a continuous-ash-discharge spreader-stoker system ideally suited for firing RDF (undergrate-air distribution can be adjusted to allow for fuel flow and property variations common to RDF)

- since the unit is equipped with both low-set mechanical coal distributors and high-set mechanical cellulose distributors, RDF and d-RDF can readily be cofired with a minimum of feeder modifications. Densified RDF can be mixed with either stoker coal or bark and fed through the existing mechanical distributors or it can be fed separately in the high-set distributors without mixing. Existing high-set cellulose distributors can be replaced with pneumatic distributors when firing RDF. A high-pressure air system would be required for the distributor system and overfire air

- the unit is designed with a low heat release rate furnace to accommodate a variety of solid fuels with varying properties and, due to the large furnace volume, sufficient retention time is available to allow complete combustion of the RDF

- the boiler-bank area has a single pass without any baffling to keep turbulence and flue-gas velocity down and to reduce erosion problems

- the superheater and boiler-bank transverse-tube spacing is sufficiently wide to prevent ash bridging and accumulations that could adversely affect heat transfer efficiency

- adequate sootblower coverage in the boiler bank and superheater sections is provided to ensure thorough ash removal and tube-surface cleaning

- the unit is equipped with a continuous fin economizer and tubular air preheater, which are the preferred methods of heat recovery in the convective zones due to their resistance to ash plugging

- the final steam temperature (750°F) is sufficiently low to prevent serious acid-corrosion problems

The use of RDF in combination with coal in this unit will affect boiler performance only slightly, provided the percentage of RDF by heat input is kept relatively low. As described previously, the limit of RDF utilization depends largely on unit design and the performance margins of auxiliary equipment such as fans, ash-removal system, and pollution-control systems. The degree of furnace slagging and superheater and boiler-bank fouling, determined by actual operation only, are other important limitations.

This particular unit is designed for 120,000 lb steam/hr at maximum continuous rating (MCR) on coal and bark. On 100 percent coal firing, this rating increases to 150,000 lb/hr. Based on maintaining 120,000 lb/hr steam flow with coal as the primary fuel, the maximum recommended use of RDF is 20 percent by total heat input. However, considering some of the unit's excellent design features and its acceptability for firing waste fuels, the percent RDF utilization may be as high as 30 percent, as determined by actual boiler operation. Other performance factors of note are

- a unit of this kind burning 100-percent stoker coal can be expected to achieve approximately 80-percent boiler efficiency; however, due to the higher moisture content of RDF as compared to coal (additional heat energy is required to drive off the added moisture contributed by RDF) and the need for additional quantities of excess air to ensure full combustion, boiler efficiency will decrease as the use of RDF increases

- air and gas weights, which will increase slightly--the exact amount dependent on the quantity of RDF burned--may affect the capability of FD and ID fans to handle the increased flow. Whether or not sufficient fan capacity is available will be dependent on the margin of fan capacity overdesign.

- superheater outlet steam temperature and pressure should remain the same when burning 20-percent RDF as when burning 100-percent coal, although actual operations may result in some fouling of heat-transfer surfaces, which would adversely affect final steam conditions

- flyash loading can be expected to increase accordingly as the percentage of RDF use increases. For every one percent utilization of RDF by total heat input, the flyash loading is expected to increase by one percent from that on 100 percent coal firing. If RDF is burned at a rate of 20 percent, an increase in flyash loading at the inlet to the air-pollution control system can be anticipated. Its overall effect on the system can only be determined during actual operation.

Boiler Modifications and Projected Costs

Modifications. Depending on the original unit design configuration, selected modifications may be required to properly retrofit boilers to effectively burn RDF. Units designed to fire a variety of solid fuels will generally require few changes to accommodate RDF. However, units burning a single fuel, with less flexible designs, may require more extensive modifications.

A primary consideration is the retrofitting of additional feeders or modifications to existing ones to handle the refuse fuel. In some cases, existing feeders can simply be removed from their furnace openings and replaced with new feeders designed to distribute RDF, d-RDF, or fuel blends.

Should it be necessary to retrofit additional feeders onto the boiler, new furnace openings would be required. Installation of bent-tube inserts would be necessary to form openings through pressure parts (water wall tubes). This procedure would involve cutting out tube sections large enough to accommodate the feeder and reconnecting the tubes with specially fitted bent-tube assemblies (Fig. 22). The retrofit of distributors through pressure parts must be above the lower water-wall header (manifold) and it must also allow adequate clearance from auxiliary oil burners, ducts, and existing overfire air-ports located in the furnace sidewalls. These considerations are very much site-specific.

Included in a retrofit feeder installation are distributor seal boxes and assorted mounting plates and structural steel supports as well as refractory, insulation, and casings to complete patch-up work.

Additional secondary air may be necessary in order to efficiently burn the refuse fuel. An overfire air source, either high- or low-pressure, is generally located several feet above fuel distributors. If pneumatic distributors are installed, a distributor air system with a separate high-pressure fan (30 in. W.C.) and associated ducting, piping, and a manual butterfly-valve damper would be required. Low-pressure air can be tapped from the forced-draft (FD) fan air system, which generally has an operating pressure of 10 to 12 in. W.C.

Costs. Total unit costs for modifying a boiler to burn RDF will depend on the unit's design characteristics and on the degree of modifications required. In the case of the VU-50 and VU-40 units evaluated previously, the degree of modification and associated costs will vary significantly based on each unit's suitability for firing RDF. Since the VU-50 is less suitable for burning RDF than the VU-40, more extensive modifications will be required and its retrofit costs will be higher accordingly.

As a means of determining approximate costs to modify existing boilers for properly burning RDF as a supplemental fuel, costs for various component systems and equipment need to be developed. Based on information supplied by Combustion Engineering, material cost estimates were developed for retrofitting RDF pneumatic distributors into the furnace front wall (pressure parts). This is the primary modification required on most units to feed fluff RDF material into the furnace. As stated earlier, d-RDF can readily be fed through existing mechanical distributors; feeder and pressure part modifications would, therefore, be minimal. It should be stressed that the costs given here are approximate costs only and that they are not intended to be absolute values. They were developed to be used as a gauge for the order of magnitude cost for future modifications (appropriate inflation factors were not included).

Please note also that labor and design and engineering costs were not included. These can be estimated from appropriate factors.

The approximate material costs for the installation of three 24-in.-wide pneumatic distributors and associated air supply system are given as follows:

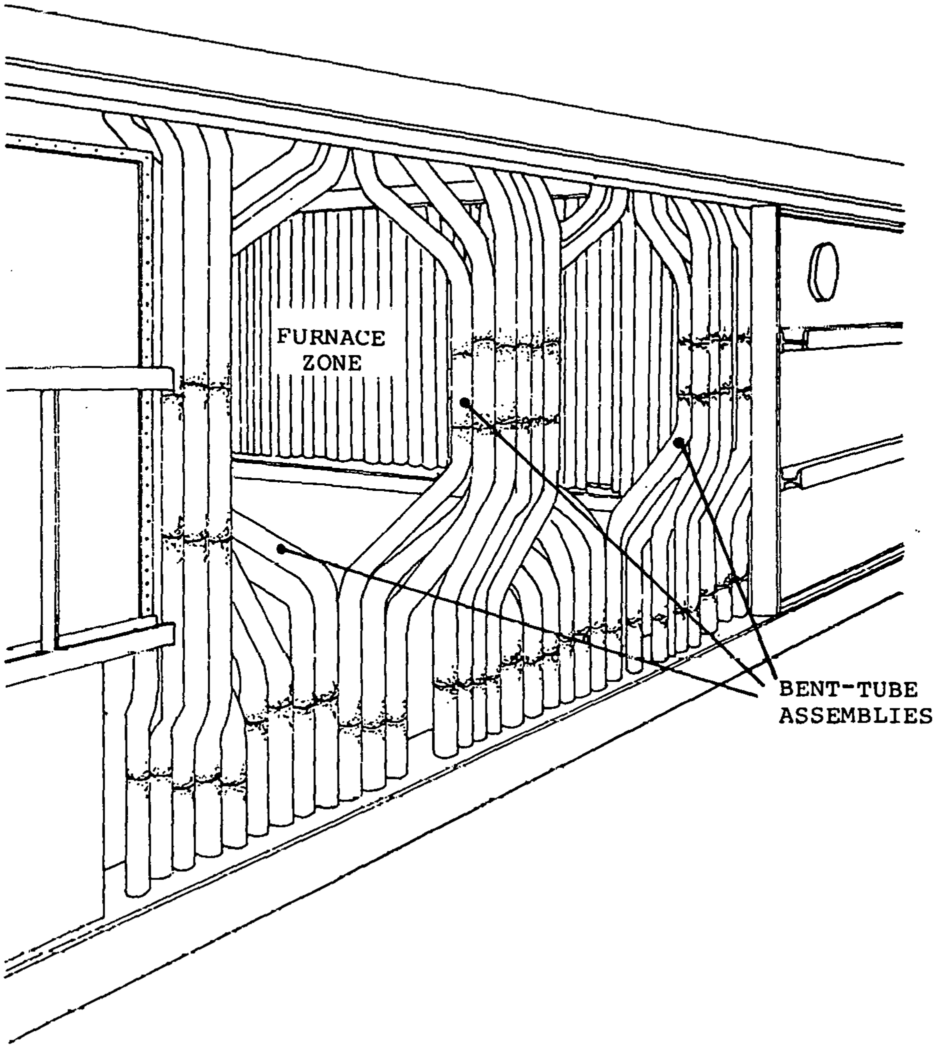

Figure 22. Bent-Tube Inserts for Installation of Fuel Distributors

three 24-in. feeders rated at 12 tons/hr each	$35,500
three sets of distributor seal boxes	5,500
refractory materials	3,500
high-pressure fan rated at 30 in. W.C. static pressure; 2000 CFM, plus 5 h.p. electric fan motor	14,000
electrical controls	5,500
	$64,000
materials for three bent-tube inserts in front wall pressure parts (if required)	17,500
	$81,500

Miscellaneous costs (not provided here) might include air ducts and air-distribution headers, furnace overfire air-injection nozzles, and structural supports. Other costs relating to fuel storage, metering, and transport to the boiler interface were not included as part of this evaluation.

Corrosion Potential when Firing RDF

Due to various chemical constituents in municipal refuse, the potential for serious tube-metal corrosion increases as the utilization of RDF as a supplemental fuel increases. The presence of chlorides in the effluent gas stream when burning RDF (introduced in the form of polyvinyl chlorides in plastics) increase the corrosion potential due to general acid attack or stress corrosion fatigue. Unless certain design and operating procedures are followed, high maintenance costs and reduced unit availability can result.

At least four known mechanisms of corrosion must be considered in any unit evaluation: (1) high-temperature liquid-phase corrosion; (2) corrosion from nonuniform furnace atmosphere; (3) corrosion by hydrochloric acid; and (4) low-temperature dew-point corrosion. A brief discussion of each follows.

High-temperature liquid phase corrosion is a rather complex process, but is generally agreed to be temperature dependent and to occur in locations such as superheaters, where high metal temperatures (>850°F, see Fig. 11) allow deposits to exist in a molten state (Ref. 3). This process involves sulfates, chlorides, and alkali materials, and is attributable to the relatively low ash-softening temperature of RDF. Coal ash, in the proper proportion, tends to neutralize molten RDF ash both chemically and physically to produce a deposit that does not readily adhere to tube surfaces. Liquid-phase corrosion can be minimized by designing for low furnace exit-gas temperature, a uniform oxidizing atmosphere, superheater metal temperatures below 850°F, adequate sootblower coverage, and localized tube shielding.

Corrosion from nonuniform furnace atmosphere is caused by the products of partial combustion in a local reducing atmosphere or in an alternating reducing-oxidizing atmosphere in the furnace. A reducing atmosphere can be the result of insufficient excess air or the stratification or improper distribution of combustion air and fuel. This condition results in the production of carbon monoxide and hydrogen sulfide. It is believed that these gases cause wastage and tube failures by effectively reducing the iron oxide on the surface of the tubes. Reducing atmospheres also lower ash-fusion temperatures, which increases the potential for liquid-phase corrosion. It is important that the combustion system provide not only the correct fuel-air ratio, but also proper distribution of fuel and air with sufficient turbulence to prevent stratification. Proper fuel preparation, even mixing of RDF with the primary fuel, and the use of additional overfire air can minimize this condition.

Corrosion by HCl, of particular concern in the superheater region, involves the release of HCl from within tube deposits as oxidizing sulfur compounds displace chloride from the deposits. Subsequent reactions may involve the stepwise formation of volatile ferric chloride and/or unstable chloride and/or oxychlorides of other alloy components (Ref. 4).

Low-temperature dew-point corrosion occurs when flue gases contact metal surfaces that are at temperatures below the dew point of the corrosive constituents in the gas. As shown in Figure 11, corrosion starts to increase significantly as the gas or metal temperature approaches 300°F. Areas especially subject to this corrosion are the cold end of an air preheater, the water inlet of an economizer (if the feedwater temperature is too low), ID fans, air-preheater cold-end ducting and air-pollution control equipment. In areas where the flue gas is cooler, SO_3 reacts with water to form sulfuric acid. If the gas temperature is below the dew point, condensation occurs and the resulting acid attacks exposed metal surfaces. Wastage of this type can be controlled or eliminated by maintaining metal and gas temperatures above the dew point, by eliminating SO_3 from the flue gas, or, in some cases, by the use of special alloys and coatings resistant to acid attack (Ref. 1). Since RDF is generally a low-sulfur fuel, proper design and operating procedure should help minimize dew-point corrosion.

Low-temperature corrosion could also be a problem during unit outages. Some deposits are corrosive and, where the deposits are hydroscopic, the problem becomes more severe as the length of the outage increases. If a lengthy shutdown is contemplated, the fireside of the unit might be water-washed with an alkaline solution or kept hot by using an external heat source (Ref. 3).

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3. Fernandes, J. H., and R. C. Shenk, "The Place of Incineration in Resource Recovery of Solid Waste," presented at the Sixth ASME National Incinerator Conference, Miami Beach, Florida, May 12-15, 1974.

4. Petersdorf, R. J.; S. M. Sansome; A. L. Plumley; W. F. Roczniak; and C. R. McGowin, "Co-Firing Coal and Refuse-Derived Fuel in a Utility Steam Generator: Operational Experience and Corrosion Probe Evaluation," presented at the American Power Conference, Chicago, Illinois, April 21-23, 1980.

SECTION 6

CONCLUSIONS AND RECOMMENDATIONS

Concept

The basic concept behind a mobile RDF production system is sound since it provides an opportunity for potential RDF producers and users to test the fuel, which they could not otherwise do so without assuming high economic risks. By capturing local conditions (related to waste properties and boiler characteristics), the program can provide the impetus needed to promote commercialization of resource recovery.

Questions regarding the benefits of a mobile RDF production system versus a fixed production facility have been raised during these evaluations. And arguments can be made concerning the technical and economic benefits of each approach. These were not addressed since a comparison of the two approaches was not within the scope of this study.

Producer/User Interest and Concerns

Although potential fuel producer and user groups expressed interest in the program to varying degrees, no firm commitments to participate were secured from either group. There seem to have been several reasons for this.

In attempting to locate and secure Agreements of Participate from producer/user groups, it was determined that the fuel user location, boiler configuration, and projected fuel economics and supply were the most critical factors. At the same time, boiler owners and operators recognized that the quantities of RDF to be tested were insufficient to resolve their concerns regarding potential tube-metal corrosion, and some were concerned that the tests might expose potential environmental hazards concerning air emissions and boiler-ash residues. As a whole, the user groups expressed a preference for d-RDF as a supplemental fuel to facilitate use of existing fuel-handling, feed, and firing equipment.

Firm commitments by users to participate in the program were also inhibited by uncertainties regarding test scheduling and program costs. The potentially long lead time to testing (from three to five years) was noted as being much longer than acceptable for effective fuel-use planning. Uncertainties also remained regarding the extent to which potential Burn Agents would be responsible for costs incurred from their participation in the program. Of particular concern was the cost to modify boilers to burn fluff RDF. DOE will, in all probability, have to assume the bulk of the costs if boiler modifications are required.

The user groups contacted were definitely not receptive to the hard line approach contained in the original Draft Agreement to Participate, which required their commitment to the long-term purchase of RDF upon completion of successful testing. Such an agreement would preclude their maintaining the planning and purchasing flexibility necessary in light of variable fuel-supply and environmental conditions.

The potential fuel producer groups contacted generally had fewer qualifications and concerns regarding their participation in the program. As with the user groups, concerns were expressed regarding the financial responsibilities related to participation. Those groups familiar with resource-recovery technology were concerned with the operation and maintenance of equipment in the field, particularly the pelletizing machines, due to reported problems concerning reliability and operating costs.

Another concern expressed by some individuals involved in solid waste management planning involved the potential that the Mobilizable Program might delay or even stall the implementation of other waste-disposal or resource-recovery options. There was concern that local agencies might await the outcome of testing before implementing alternate plans, resulting in potential delays of several years.

System Design and Procurement

The key criteria in design and construction of the mobile system (fuel production and boiler feed equipment) is that the equipment be both simple and reliable for operation and maintenance in a "field" environment. Problems resulting from operation of the equipment (and resulting delays) would be highly visible and could serve to detract from the intent and potential benefits of the program.

A single System Equipment Contractor with total turnkey responsibility for final design, fabrication, assembly, and shakedown of the system is recommended. In addition, this agent would supply a technical service representative to assist in operator training and maintenance supervision of each test location. The use of a single agent would fix warranties and performance guarantees with one group only.

In addition to the concerns expressed regarding operation of the pelletizer, questions regarding the exact design and operation of the tramp metal separator/detector were raised. Due to current and anticipated future development of such equipment, an operable unit should be available for inclusion in the mobilization production system.

System Costs and Future Scheduling

The estimated cost for each of the three RDF/d-RDF production systems and the two fuel-receiving, meter, and feed systems developed in Section 4, are shown in Table 18. Table 18 also summarizes the combined cost of mobile production and feed-systems procurement costs.

Note that costs of retrofitting boilers for burning RDF (developed in Section 5) were not included. The cost of such modifications can vary greatly depending on unit design configuration and existing fuel and fuel-handling systems. Because these costs will be recurring at a number of the test sites over the course of the mobilizable program, they will be significant, in total, relative to the overall program costs.

Once a decision has been made to provide and fund a Mobilizable Program, it is anticipated that approximately 15 to 18 months would be required to issue an RFP, select a Systems Equipment Contractor, prepare final designs, procure and assemble the equipment, and perform shakedown testing. Testing could then proceed at two or three individual sites per year.

Table 18. Cost Summary of Mobile Equipment Systems

Production System	Cost
RDF	$1,206,000
Baled RDF	1,292,000
d-RDF	1,768,000
Feed System	
Battelle (RDF)	$ 247,500
Canada Cement (baled RDF)	225,000
Combined Cost Summary (production and feed system)	
	Cost
RDF/Battelle System	$1,453,500
Baled RDF/Canada Cement System	1,517,000
d-RDF (production system only)	1,768,000

Appendix A

Draft Agreements for Prospective RDF Production Agents

A-1. "Letter of Intent" to Participate

A-2. Equipment Operating Agreement

A-3. Production Schedule

A-1. "Letter of Intent" to Participate

Dear

The "XYZ Corporation" has considered the documentation provided by NCRR which details the responsibilities of the Production Agent in a program to determine certain materials handling, combustion, and emission characteristics of cofiring RDF along with traditional fuels in industrial boilers. If were to consider a program of the type outlined in the documents provided, our company would agree to act as the Production Agent for the RDF to be used in the Test Burn at (location). Furthermore, it would be our intent to respond to a Purchase Order for long-term RDF production if offered by the Burn Agent.

It is our understanding that the Mobilizable Test Program will, if approved, be implemented within the next 24 months. Our expression of intent is based upon this assumption and the successful negotiation of contracts with DOE consistent with the drafts we have reviewed.

Sincerely,

XYZ Corporation

A-2. Equipment Operating Agreement

An operating agreement between "XYZ Corp./Public Entity" hereinafter referred to as the Production Agent and the . The Production Agent desires to produce Supplementary Fuel (RDF) for the (fuel customer) hereafter referred to as the Burn Agent. To produce a sufficient amount of RDF to successfully complete a Test Burn for the Burn Agent, the Production Agent agrees to take possession of certain pieces of mobilizable RDF production equipment, hereafter called the Equipment, and to operate this Equipment at its own expense, except as otherwise indicated in this agreement, to produce a quantity of RDF as indicated in the "Production Schedule."

The Production Agent agrees to receive the Equipment designated Transportation Agent at (insert Production Agent's operating location) and to release same to the Transportation Agent at the conclusion of the Test Burn.

The Production Agent agrees to maintain the Equipment while in his possession and will allow . or its representative to inspect the Equipment at any time while in his possession.

The Production Agent agrees to keep maintenance records on the Equipment in a manner prescribed . The Production Agent will submit invoices to for any maintenance and repair expenses it incurs while operating the Equipment that are reimbursable under the terms of the maintenance budget provided for the Equipment. Such invoices will be submitted on a form to be provided [1] The Production Agent agrees to operate the Equipment in a manner consistent with industrial safety practices. The Production Agent agrees to provide liability insurance for Equipment in an amount to be specified . The Production Agent agrees to conform to any and all state and local ordinances applicable to the operation of the Equipment while it is in his possession.

This agreement shall become effective when the Equipment is received by the Production Agent at the Production Location and terminate when the Equipment leaves the Production Location.

________________________________ ____________________________
Production Agent

[1] Since the equipment configuration will vary with the type of fuel to be produced, a maintenance budget will be provided to each Production Agent on a site-specific basis. The budget will be based on the amount of fuel to be produced and the "expected usage" that the Equipment will receive. Examples of this include retipping of the shredder hammers prior to the start of production or some type of electrical repair work that necesitates the use of a local electrical contractor.

A-3. Production Schedule

This document constitutes an agreement between DOE and the XYZ Corp., hereafter called the Production Agent, whereby the Production Agent will take possession of certain pieces of "Mobilizable Refuse-Derived Fuel Processing Equipment" as outlined in Appendix A of the Operating Agreement and operate this equipment to process municipal solid waste into Refuse-Derived Fuel.

The schedule below assumes an equipment suit that will process about six tons of MSW per hour and produce about three tons of RDF per hour. A seven-to-ten-week production run for each Test Burn is assumed and is obtained by working eight hours per day, five days per week.

The Production Agent declares that it is his intent to process 1,500 tons of MSW using this equipment and to produce 750 tons of RDF.

This fuel will be produced to meet the following schedule:

A. On or before (Date), 120 tons of RDF will be delivered (available for delivery) to the Burn Location.

B. On or before (Date), 240 tons of RDF will be delivered (available for delivery) to the Burn Location.

C. On or before (Date), 360 tons of RDF will be delivered (available for delivery) to the Burn Location.

The Production Agent will coordinate the transportation of RDF with the Burn Agent to assure consistency of delivery with the Burn Agent's storage requirements.

XYZ Corporation

____
Department of Energy

Appendix B

Draft Agreements for Prospective RDF Burn Agents

B-1. "Letter of Intent" to Participate

B-2. Agreement to Participate

B-3. Test Burn Schedule

B-4. Purchase Order

B-5. Fuel Price Adjustment and Purchase Order Termination Agreement

B-1. "Letter of Intent" to Participate

Dear

The "XYZ Corp." has considered the documentation provided . which details the responsibilities of the Burn Agent in a program to determine certain materials handling, combustion, and emission characteristics of cofiring RDF along with traditional fuels in industrial boilers. We believe that it would serve the purpose of the program to conduct a series of tests such as this with our company. It is our intention to participate if embarks on a program such as is described Furthermore, it would be our intent to offer a Purchase Order for long-term RDF purchase if the measured and observed results of the series of test burns meet the criteria also developed in the documentation.

It is our understanding that the Mobilizable Test Program will, if approved, be implemented within 24 months. Our expression of intent is based upon this assumption and the successful negotiation of contracts with DOE consistent with the attached drafts.

Sincerely,

XYZ Corporation

B-2. Agreement to Participate

The XYZ Corp., hereafter referred to as the Burn Agent, declared that it is its intent to test burn a refuse-derived fuel (RDF), herein referred to as the Supplementary Fuel, in the boilers of its facility at (Burn Location).

The Burn Agent, in conjunction with the Test Agent, also agrees to participate in a series of tests to determine if the Supplementary Fuel meets established criteria, as described in the Criteria Determining the Issuance of a Purchase Order section of the Information Document. The Burn Agent further agrees and commits itself to a Purchase Order if the criteria established for the Test Burn are successfully met.

The Supplementary Fuel will be delivered by the Production Agent to the Burn Location commencing on (insert date that reflects the Production Schedule agreed upon by the Production Agent).

The Burn Agent agrees to burn the Supplementary Fuel according to a predetermined Test Burn Schedule. This Schedule will specify the dates, duration, and amounts of Supplementary Fuel for each of the burns that will be conducted.

If, for any reason, the Production Agent fails to supply sufficient fuel for the Burn Agent to complete a scheduled burn, the burn will be considered invalid and will be rescheduled for a date when a sufficient amount of fuel is available.

The Production Agent will be responsible for the transportation of the Supplementary Fuel to the Burn Location and for coordinating his deliveries at a rate consistent with the storage capability at the Burn Location and the demand for Supplementary Fuel in the particular test series being conducted.

Signed,

XYZ Corporation

B-3. Test Burn Schedule

This document constitutes an Appendix to the Agreement to Participate and is incorporated by reference. This document is an acknowledgment by the Burn Agent that the following amounts of RDF will be delivered to the Burn Location for the purchase of a Test Burn. The terms and conditions of the Test Burn have been outlined to the Burn Agent in the prior Agreement to Participate and he is prepared to receive and burn RDF produced by the Production Agent at the time and in the amounts listed in the following Test Burn Schedule:

A. On or before (Date), 120 tons of RDF will be delivered (or available for delivery) to the Burn Location.

B. On or before (Date), 240 tons of RDF will be delivered (or available for delivery) to the Burn Location.

C. On or before (Date), 370 tons of RDF will be delivered (or available for delivery) to the Burn Location.

The Production Agent will coordinate the transportation of RDF with the Burn Agent to assure consistency of delivery with the Burn Agent's storage requirements.

XYZ Corporation

____
Department of Energy

B-4. Purchase Order

The "XYZ Corp.," hereinafter called the Burn Agent, offers to purchase from the Production Agent a quantity of RDF, hereafter referred to as the Supplementary Fuel.[1] The terms and conditions of this purchase are as follows:

Part A - Fuel Quantity and Delivery

The Burn Agent agrees to purchase a minimum of 250 tons of Supplementary Fuel each year from the Production Agent for a period of ten years.[2]

The Supplementary Fuel shall have the following characteristics, computed on a "wet weight" or "as-received" (i.e., includes the weight of moisture):

Parameter	Mean	Standard Deviation[3]
Higher Heating[4] Value (Btu/lb)	550	600
Ash (%)	12	4
Moisture (%)	22	5
Sulfur (%)	0.2	0.1
Chlorine (%)	0.3	0.1

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[1]A competitive bid procedure, rather than the "follow-on" form used here, can also be used.

[2]The following assumptions are used when calculating the amount of RDF that would be burned by a 100,000 lb/hr industrial boiler.

Average boiler load - 75 percent (75,000 lbs of steam/hr.)

Heating value of RDF - 5500 Btu/lb

Boiler efficiency - 65 percent

Steam Enthalpy - 1200 Btu/lb

Boiler operating time - 24 hr/day, 6 days/wk, 52 weeks/yr

a. Minimum Tonnage (based on 10 percent heat input from RDF):

$$100{,}000 \frac{lb}{hr} \times 0.75 \times 24 \frac{hr}{day} \times 6 \frac{days}{week} \times 52 \frac{weeks}{yr} \times 0.10 \text{ RDF} \times 1846 \frac{Btu}{lb\ steam} \times 1 \frac{lb\ RDF}{5500\ Btu}$$

$$\times 1 \frac{ton\ RDF}{2000\ lb\ RDF} = 9425 \text{ Tons/yr} = 181 \text{ Tons/week}$$

b. Maximum Tonnage (based on 30 percent heat input from RDF):

$$100{,}000 \frac{lb}{hr} \times 0.75 \times 24 \frac{hr}{day} \times 6 \frac{days}{week} \times 52 \frac{weeks}{yr} \times 0.30 \text{ RDF} \times 1846 \frac{Btu}{lb\ steam} \times 1 \frac{lb\ RDF}{5500\ Btu}$$

$$\times 1 \frac{ton\ RDF}{2000\ lb\ RDF} = 28{,}274 \text{ Tons} = 544 \text{ Tons/week RDF}$$

[3]The standard deviation is a statistical term that describes the average range that each value lies from the mean of a set of values. Mathematically the standard deviation is defined as

$$\sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{N-1}}$$

[4]The Higher Heating Value (HHV), or gross calorific value, of a fuel is defined as "the heat produced by combustion of unit quantity of a solid or liquid fuel when burned at constant volume in an oxygen bomb calorimeter under specified conditions, with the resulting water condensed to a liquid." (ASTM D 121-78 Standard Definition of Terms Relating to Coal and Coke). HHV can be reported on a weight basis, either including ("wet") or excluding ("dry") the weight of moisture.

These fuel characteristics shall be determined by the methodology described in Appendix A to this Purchase Order.

The Supplementary Fuel will be transported by the Production Agent to the Burn Agent's facility in a manner acceptable to the Burn Agent.

The Burn Agent will accept delivery of this fuel during normal business hours and will keep the Production Agent informed of any changes in this procedure.

The Burn Agent will work with the Production Agent to assure a steady flow of Supplementary Fuel. The Burn Agent agrees that, in no instance, except those instances defined in the "Force Majeure" section of this Purchase Order, shall he refuse to accept less than ___ tons of Supplementary Fuel weekly at his facility.[2]

The Burn Agent further declares that he will not be required to accept more than ___ tons of Supplementary Fuel in any one week.[2]

The Burn Agent recognizes the seasonal nature of waste generation and promises to make his best efforts to accommodate the requirements of the Production Agent in this regard.

A system of weighing and recording the quantities of Supplementary Fuel delivered to the facility shall be developed by the Production Agent and approved by the Burn Agent. The Burn Agent reserves the right to "spot check" this system without prior notice to the Production Agent. The Burn Agent will notify the Production Agent as soon as any disparities in the weighing and recording system are discovered and make all good faith efforts to resolve the matter.[5]

Part B - Sampling and Analysis

In order to determine the characteristics of the Supplementary Fuel, a representative sample shall be taken at the firing point intake of the Burn Agent's boiler by the Burn Agent each day, or such other place and regular time interval as may be agreed upon, during which Supplementary Fuel is burned in the boilers. The Production Agent shall have the right to witness all sampling. All samples shall be divided into three (3) parts and put in suitable airtight containers. One part shall be retained by the Burn Agent and such part shall be analyzed by the Burn Agent, and the results reported to the Production Agent for its own analysis as a check on the Burn Agent's analysis; and the third part shall be retained by Burn Agent in one of the aforesaid containers, properly sealed and labeled, to be analyzed later if a dispute arises due to a difference between the Burn Agent's and the Production Agent's analyses. Each party shall assume the cost of analysis of its part of the sample.

Should analysis of the third part of any sample be found necessary, such analysis shall consist of four separate analyses made by an independent commercial testing laboratory, mutually chosen, and the average of the results of such analyses shall be controlling. The results of the analyses shall be supplied to both parties. The cost of the analyses made by such commercial laboratory shall be shared equally by both parties.

If the Burn Agent is for any reason unable to sample any shipment of Supplementary Fuel delivered hereunder, a sample taken by the Production Agent at the processing plant shall be used. The Burn Agent shall have the right to witness such sampling. If no sample is taken, an average analysis of the last three daily samples taken prior to the delivery day in question will be used.

Part C - Price

The Burn Agent offers to pay the Production Agent for Supplementary Fuel delivered hereunder at a rate equal to 75 percent of the price the Burn Agent pays for the fuel displaced. The price for the Supplementary Fuel, referred to as the Base Supplementary Fuel Price, shall be the cost for each million British thermal units (Btu) of heat content of the Supplementary Fuel. The Btu content of both the Primary and Supplementary Fuels shall be defined as the higher heating value, reported on a "wet weight" (including the weight of moisture) basis.[4]

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[5]Weighing systems will depend largely on the type of fuel used and how it is stored. The intent of the purchase-order language is to set the framework for the price-determination section.

Payments to be made by the Burn Agent shall be computed by the Production Agent by multiplying total tons delivered times the Btu-per-pound content of samples analyzed by the Burn Agent for that day times 2,000 pounds times the Base Supplementary Fuel Price divided by one million Btu. This computation for each day is described in the following formula:

Payment for Supplementary Fuel = Tons

Delivered x 2,000 lb/ton x Btu/lb Base

Supplementary Fuel Price ÷ 1 million Btu

Part D - Force Majeure

No Party shall be liable for delays or failure caused by acts beyond its control, such as strikes; riots; civil disorders; or acts of God, including fire, hurricane, wind damage, or water damage.

Notice of force majeure by one Party shall be promptly delivered to the other Party. Notice of the declaration of force majeure shall be deemed to continue until notice is provided by the declaring Party that force majeure has terminated.

Part E - Assignment

The Production Agent may not assign this agreement to any other party or corporation without concurrence of the Burn Agent.

Signed

XYZ Corporation

B-5. Fuel Price Adjustment and Purchase Order Termination Agreement

	Purchase Order Price of RDF
Original Purchase Order, including the Base Supplementary Fuel Price (BSFP), signed and in effect.	
Burn Agent determines increase in boiler operating costs due to burning RDF and prepares a new BSFP.	1. 30 days-BSFP
New BSFP is submitted to Production Agent for evaluation.	2. 30 days-1/2 BSFP for fuel delivered
Production Agent accepts or rejects the new BSFP. A 50 percent reduction in BSFP automatically takes effect if a new BSFP is rejected. If a new BSFP is accepted, Purchase Order is still valid.	3. 120 days-1/2 BSFP for average monthly delivery
If a new BSFP cannot be negotiated, Burn Agent may issue a Notification of Intent to Terminate Purchase Order. Upon receipt of such notification, Production Agent will prepare a Termination Expense Report (TER).	4. 60 days-1/2 BSFP for average monthly delivery
The TER is submitted to the Burn Agent by the Production Agent.	5. 60 days-1/2 BSFP for average monthly delivery
The TER is either approved or disapproved by the Burn Agent. If approved, the Burn Agent agrees to pay the Production Agent according to the terms in the contract. If disapproved, the Burn Agent will pay 50 percent of the BSFP on a monthly basis until a TER is approved by a court of appropriate jurisdiction. In either case, payments by the Burn Agent from the new-BSFP rejection point will accrue toward the payment of the final TER.	6. No time limits--1/2 BSFP for average monthly delivery
The final TER is approved in court. The Burn Agent pays 50 percent of TER expenses.	7. 1/2 TER

Appendix C

Manufacturer Equipment Specifications and Costs

C-1. Rotary Trommel Screens

1) Manufacturer: MAC Equipment, Inc.

Model: Mobile MSW Trommel

Capacity: 8 TPH

Size: 8 ft ID; 20 ft long; 45-in.-diameter screen holes on 6-in. centers

Power: 50-h.p. drive system with Falk reducer

Includes:

- dust cover
- 3/8-in.-thick panel screens
- 4-wheel support
- MSW receiving hopper
- infeed belt conveyor: 48 in. wide x 12 ft long;with cleats and side walls
- undersize discharge hopper with conveyors: (one) 36 in. wide x 13 ft - 6 in. long; (one) 36 in. wide x 8 ft long
- oversize material discharge conveyors: 48 in. wide x 8 ft long; with cleats and side walls
- control system with motor starters, cabinet and main disconnect
- low-boy trailer, 8 ft wide x 46 ft long

Cost: $155,000

2) Manufacturer: The Heil Co.

Capacity: 8 TPH

Size: 8 ft ID; 20 ft long; 4.5-in.-diameter screen holes

Power Requirements: 30 h.p. drive motor

Includes:

- dust enclosure
- 0.5-in.-thick bolt and screens
- infeed conveyor with hopper and sides: 48 in. wide x 15 ft long
- undersize residue conveyor: 48 in. wide x 15 ft long
- oversize material discharge conveyor: 36 in. wide x 10 ft long
- control system: motor starters and cabinet
- trailer: 8 ft wide x 40 ft long drop-back

Cost:

Trommel screen	$100,000
Electrical control system	5,000
Materials conveyors	15,000
40-ft drop-back trailer	14,000
	$134,500
Design and engineering	13,500
TOTAL COST	$148,000

C-2. Magnetic Separators

1) Manufacturer: Stearns Magnetics Inc.

Model: 25-A

Type: In-line, self-cleaning electromagnetic separator

Capacity: 9 TPH

Power Requirements: 1.5 h.p. belt motor drive; 2500 watts, 115 VDC magnet

Weight: 2900 lb

Size: 72 in. long x 30 in. wide x 37 in. high

Includes:

- cleated rubber belt, 25 in. wide
- V-belt transmission, shaft-mounted reducer
- 1-1/2 h.p., 3/60/230-460 TEFC motor drive
- silicon rectifier: output - 2.5 kw, 115 VDC; input required - 240/480 VAC; Nema Type 12 electrical enclosure

Cost:

Model 25-A magnet	$ 5,400
Rectifier	1,375
Support structure and discharge chute	5,000
TOTAL COST	$11,775

2) Manufacturer: Dings Co.

Model: #55

Type: In-line, self-cleaning electric overhead magnet

Capacity: 15+ TPH

Power Requirements: 3 h.p. belt drive motor; 7875 watts, 115 VDC magnet

Weight: 7420 lb

Size: 116 in. long x 60 in. wide x 28 in. high

Includes:

- 50-in.-wide heavy-duty SS cleated belt
- V-belt drive and reducer
- 3 h.p., 3/60/240-480 TEFC motor drive
- silicon rectifier: output 8 kw, 115 VDC; input 3/60/240-480 VAC; Nema 12 electrical enclosure

Cost:

Model #55 magnet	$12,440
Silicon rectifier	2,400
Support structure and discharge chute	7,500
TOTAL COST	$22,340

C-3. Shredders

1) Manufacturer: The Heil Co.

Model: 42 D mobile vertical refuse shredder

Capacity: 5 to 8 TPH

Unit Size: 37.5 ft long x 9.5 ft wide x 13 ft - 9 in. high

Weight: 26.6 tons

Power Requirements: no external power needed with diesel drive system
200 h.p. electric main drive (optional)

Shredder product: 4 in. nominal (1-1/2 in. possible with hammer modifications)

Includes:

- 180 h.p., 6 cyl., water-cooled, 12 V, electric start, Detroit diesel shredder drive motor
- 200 h.p., 3/60/440 V electric drive motor (optional)
- 12 h.p., 4 cyl., air-cooled, 12 V, electric start, gasoline generator motor
- 230 VAC, 15.7 A, 60 Hz, 6.2 KVA generator
- hard-faced steel hammers
- cast manganese steel shredder walls
- 1200 rpm shredder shaft speed, belt driven
- 42 in. wide x 11 ft long loading conveyor, 4-ply belt with feed hopper
- 48 in. wide x 16.5 ft long infeed conveyor, 4-ply belt, with 2 h.p. motor
- 36 in. wide x 9 ft - 9 in. long discharge conveyor, 4-ply belt, with 1-1/2 h.p. motor
- 30 in. wide x 10 ft long transverse discharge conveyor, 4-ply belt with 1.0 h.p. motor
- shredder speed sensor cut-off unit
- 5-7/8-in.-diameter, vertical main shredder shaft
- pushbutton control panel with motor starters
- ballistic reject system
- 2-axle trailer with adjustment stabilizers

Cost:

42D mobile shredder unit with optional 200 h.p. electric drive (replacing diesel motor drive)	$300,000

C-4. RDF Balers

1) Manufacturer: International Baler Corp.

Model: NA-1295 horizontal baler

Capacity: 3-5 TPH

Baler Dimensions: 18.5 ft long x 5 ft wide x 6 ft high

Power Requirements: 30 h.p. electric motor

Bale Size: 6 ft x 4 ft x 3 ft

Bale Weight: 1500 - 1800 lb (average)

Cycle Time: 25 s

Overall Platen Pressure: 78,000 lb

Includes:

- 30 h.p., 3/60/230-460 V electric motor and starter
- NEMA 12 controls enclosure
- automatic bale sizer
- 50 in. x 46 in. feed opening with hopper
- shear bar
- hydraulic door cylinders
- fully automatic push bottom control
- LED-full bale buzzer

Cost:

NA-1295 horizontal baler as above	$29,995
Roller conveyor discharge	1,000
TOTAL COST	$31,000

2) Manufacturer: Balemaster Div., E. Chicago Machine Tool Corp.

Model: E-660

Type: Balemaster horizontal baler

Capacity: 4.5 TPH

Baler Dimensions: 20.5 ft long x 3 ft wide x 6-3/4 ft high

Power Requirements: 25 h.p. electric motor

Bale Size: 6 ft long x 2.5 ft wide x 3 ft high

Bale Weight: 1200 lb (average)

Includes:

- 25 h.p., 3/60/230-460 V electric motor and starter
- NEMA 12 controls enclosure
- fully automatic controls
- automatic cycling eye
- automatic bale length control
- automatic bale density control
- 27 in. x 32 in. feed chute with hopper

Cost:

Model E-660 baler as above	$34,100
Roller conveyor discharge	1,000
TOTAL COST	$35,100

C-5. Densifiers

1) Manufacturer: California Pellet Mill Co.

Model: 7822-2, single-speed densifier

Capacity: 3 to 5 TPH (design)

Weight: 16,000 lb

Power Requirements: 200 h.p. main drive motor
1-1/2 h.p. oil pump motor
7-1/2 h.p. refuse distribution motor
7-1/2 h.p. live bottom feeder motor
15 h.p. conditioner/conveyor motor

Die Hole (pellet) Size: 1/2 in.

Includes:

- 200 h.p., 1200 rpm, 3/50/460 V TEFC main drive motor (1.15 service factor)
- 1-1/2 h.p. oil pump drive motor
- 7-1/2 h.p., 1800 rpm, TEFC refuse distributor motor
- 15 h.p., 900 rpm, 3/60/230-460 V TEFC conditioner/conveyor drive motor
- heavy duty gear drive
- continuous oil lube system with LP shut-off
- 600 in.^{2} alloy steel die, 170 rpm, with hoist
- two 13-in.-diameter Hard-Cote rollers
- shear pin to protect die and rollers

Cost:

Model 7822-2 densifier and auxiliary equipment as above	$100,000
Starters and controls	5,000
2 spare roller assemblies (Hard-Cote)	6,000
TOTAL COST	$111,000

2) Manufacturer: Koppers Co., Sprout-Waldron Div.

Model: 21 V-200 pellet mill

Capacity: 3+ TPH

Weight: 13,200 lb

Power Requirements: 200 h.p. main drive motor
10 h.p. feeder/conditioner motor
1-1/2 h.p. feeder/distributor motor

Die Hole (pellet) Size: 3/4 in.

Includes:

- 200 h.p., 1800 rpm, TEFC main drive motor
- 10 h.p. feeder/conditioner motor
- 1-1/2 h.p. feeder/distributor motor
- V-belt drive system
- 21 in. ID, 280 in.^{2} die area
- three 8-1/8 in. rollers
- in-line feeder/conditioner
- positive feeder/distributor to die area
- spout magnet
- 3 adjustable feed plows
- shear pin release

Cost:

Model 21V-200 pellet mill as above	$64,500
Starter and controls	5,000
Spare rollers and parts	6,000
TOTAL COST	$75,500

3) Manufacturer: Papakube Corp.

Model: Energy Cube densifier system

Capacity: 5 TPH

Weight: 12,500 lb (with trailer)

Power Requirements: 150 h.p. main drive motor
2 h.p. metering device
2 h.p. input conveyor
2 h.p. discharge conveyor

Die (cube) Size: 1-1/4 in. square, 3 in. long

Includes:

- surge hopper and metering device with level control sensor
- input conveyor: 36 in. wide x 20 ft high
- control panel, starter system and electric meters
- 150 h.p., 3/60/440 V main drive motor
- three 2 h.p. meter and conveyor motors
- safety magnet
- hook-ups for incoming 110 V or 440 V power
- 24 ft long x 10 ft wide, 3-axle trailer

Cost:

Trailer mounted Energy Cube densified system with equipment as above	$ 99,500
Downpayment to lease die assembly	5,000
TOTAL COST	$104,500

C-6. Diesel Generator Systems

1) Manufacturer: Caterpillar Tractor Co.

Models: 3412, D348, and D349 generator sets

Type: enclosed diesel engine electrical generators

General Specifications:

- model no.	3412	D348	D349
- rating (kw)	500	600	750
- weight (lb)	9,610	13,083	16,225
- size (in.)	150x82x70	155x82x70	170x82x70
Engine Specifications:			
- type	V12 diesel turbo	V12 diesel turbo	V12 diesel turbo
- h.p.	755	890	1,100
- fuel use (est., at full power output)	38 gal/hr	45 gal/hr	55 gal/hr
Generator Specifications:			
- type	brushless revolving fld, solid state exciter	brushless revolving fld, solid state exciter	brushless revolving fld, solid state exciter
- phase	3, 60 Hz	3, 60 Hz	3, 60 Hz
- connections	wye	wye	wye
- available voltages	120/240/480	140/240/480	230/460
- speed (rpm)	1800	1800	1800
Cost:	$95,000[1]	$135,000[1]	$165,000[1]

[1]Includes full motor cover for exterior use and cooling fan.

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