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RESIDUAL-ENERGY-APPLICATIONS PROGRAM: SUPPORT & INTEGRATION REPORT

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Energy Research Institute

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RESIDUAL-ENERGY-APPLICATIONS PROGRAM
SUPPORT & INTEGRATION REPORT

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ABSTRACT

This report is one of a series of documents on the EAST Facility prepared by the South Carolina Energy Research Institute during government fiscal year 1980. The proposed government-owned EAST Facility at the Savannah River Plant in Aiken, South Carolina, would provide capabilities for development and confidence testing of industrial heat pumps, high temperature bottoming cycles, low temperature Rankine cycle power generation systems, and absorption chillers. This work is one component the Residual Energy Applications Program (REAP) administered by the Assistant Secretary of Fossil Energy, U.S. Department of Energy.

The other documents in the above mentioned series provide initial considerations concerning the heat pump and power generation systems to be tested at EAST, policy, objectives and guidelines for operation of the facility, a preliminary conceptual design, and environmental data.

This report describes support and integration activities that were performed during the contract year. The various elements that impact on the EAST Facility are discussed and an assessment of the EAST Facility mission is given. The report concludes with proposed milestones, schedules, and costs for design, construction and operation of the facility.

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David B. Howard, REAP Field Program Manager, DOE, Oak Ridge.

Jay D. Bilyeu, EAST Facility Project Engineer, DOE, Savannah River.

Edward Schneider, Integrating Contractor, A. D. Little, Inc.

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I. Introduction

This report summarizes project support and integration activities related to the proposed Energy Applied Systems Test (EAST) Facility. The work was performed by the South Carolina Energy Research Institute (ERI) during the 1980 fiscal year of the Federal government. The EAST Facility is one element of the Residual Energy Applications Program (REAP) administered by the Office of Coal Utilization of the U.S. Department of Energy. Other EAST Facility activities performed under the contract during FY 1980 are documented in References 1 through 5; these are summarized briefly in this report.

Basically, the support and integration activities provided project management for the ERI EAST Facility tasks. These activities were closely coordinated with the DOE program manager to insure that the proposed EAST Facility provides the full testing needs of all elements of REAP. In response to initial DOE programmatic guidelines ERI outlined the broad capabilities of EAST and developed preliminary schedules and costs for the design, construction, and operation of the EAST Facility. This information was used by DOE and the REAP Integrating Contractor, Arthur D. Little, Inc., to develop the overall REAP Plan, last revised July 28, 1980. (6) Several elements of REAP are still being formulated and changes in this Plan are anticipated.

The present report contains two plans for the EAST Facility. One is similar to the EAST Facility plan in Reference 6, modified slightly to reflect more recent information contained in References 1 and 2. The other plan proposes an accelerated EAST Facility design and construction schedule to accelerate market penetration of heat recovery technology. The initial sections of the report provide supporting information for the two plans. Sections II and III give the background and objectives of REAP and the EAST Facility. Sections IV and V summarize the status of the REAP elements that impact on the EAST Facility and the accomplishments of each of the EAST Facility tasks. Section VI

assesses the mission of the EAST Facility in light of these developments and Section VII presents the schedules and costs for design, construction and operation of the EAST Facility.

Results of these activities have confirmed the substantial benefit that can be gained from a coordinated residual energy recovery program in the United States. They support current REAP plans to design, build and operate the government-owned EAST Facility at the Savannah River Plant to provide unique developmental testing capabilities and to accelerate penetration of heat recovery systems into the public and private sectors.

II. Background

The Residual Energy Applications Program began with 1977-1978 studies which evaluated the feasibility of utilizing the large quantities of low-grade heat being dissipated at four DOE nuclear facilities (7). One of these facilities was the Savannah River Plant which produces tritium and weapons grade plutonium in three nuclear production reactors located in Aiken, South Carolina (8). The other three facilities located in Oak Ridge, Tennessee, Paducah, Kentucky and Portsmouth, Ohio, use the gaseous diffusion process to enrich uranium (9, 10, 11). Taken collectively, the four facilities reject .28 quads annually in the form of 150-165°F water effluent. A quad is equal to 10^{15} Btu's of energy.

DOE concluded significant energy recovery at the facilities can be realized by immediate implementation of direct-use options such as greenhouse operations and lumber and grain drying. Even with full implementation of all viable direct-use options, however, most of the residual energy would go unused and thus there is a need to use heat pump and power generation systems which can convert the large quantities of reject heat to steam and electricity which have much broader applications.

The power generation systems considered for the Federal facilities were based on the Rankine cycle principle. These systems generate their power from the heated water. Individual systems would have outputs in the range of 5-45 MW. Although systems for nearly similar temperature ranges have been under development for the Ocean Thermal Energy Conversion Program (12) and the Geothermal Energy Program (13), no systems are directly applicable for the Federal facilities. Likewise, the heat pumps for the Federal facility applications were considerably larger than industrial heat pump systems now on the market and they also called for significantly higher output temperatures than now are attainable in the commercial units. It was concluded development of the proposed systems would require no major technological

breakthroughs. The components of the systems (viz., compressors, prime movers, heat exchangers and turbines) now exist. The major effort lies in optimizing the systems. Since no facilities existed for providing the developmental testing for this effort, a test facility was proposed. It was proposed the facility be located at the Savannah River Plant where use could be made of the 150°F reactor effluent. The facility has been designated the Energy Applied Systems Test (EAST) Facility.

As the scope of the EAST Facility came into focus, DOE recognized the facility might also profitably serve to directly accelerate market penetration of heat recovery technology. The tests for the Federal facility applications would provide developmental data for heat recovery systems under development. The tests for the private sector applications would provide performance and reliability data for commercially available systems. There is a very large potential for residual energy recovery and utilization in the U.S.A. About 30% of the energy consumed is now being dissipated to the environment (14), with very little now being recovered. The technologies (viz., heat pumps and power generation systems) that offer the greatest potential for recovering large quantities are currently available. The need for government involvement arises because the rate of return on investment for heat recovery systems typically makes them marginally competitive with other investment alternatives available to the private sector, and these systems frequently carry a higher risk. The latter is due primarily to uncertainty in the short and long-term reliability. In the REAP Plan (6), therefore, the EAST Facility is categorized as providing developmental testing for the Federal facility applications and also confidence testing for accelerating penetration of heat recovery technology into the private sector.

Overall management policy and program responsibility for REAP resides with the Assistant Secretary for Fossil Fuels. N.J. Gerstein of the Office of Coal Utilization is program manager in Washington. In keeping with DOE policy, the program has been

decentralized to DOE field offices. Responsibilities for execution of the overall program rest with the Oak Ridge Operations Office, D. B. Howard, Program Manager. Contracting and technical responsibilities for the EAST Facility project rest with the Savannah River Operations Office, J. D. Bilyeu, Project Engineer, and D.C. Drennon, Contract Specialist.

There are numerous other participants in the program. Arthur D. Little, Inc. serves as Integrating Contractor to assist the DOE managers in directing the many elements of the program. There is, therefore, considerable interaction and feedback between ADL and the South Carolina Energy Research Institute, since the latter has primary responsibility for performance of technical and financial planning for the EAST Facility and for developing its requirements. Ed Schneider is the principal contact at ADL. E. I. duPont de Nemours and Company, the prime contractor at the Savannah River Plant, has been proposed for design, construction and operation of the EAST Facility; hence, ERI also regularly interacts with them. David R. Muhlbaier and J.P. Morin are the principal contacts at DuPont.

III. Project Objectives

The objectives of the Residual Energy Applications Program are given in the REAP Plan: (6)

- Conduct realistic feasibility experiments to recover residual heat energy in real world environments.
- Effectively use residual energy from the DOE Production Facilities (i.e., the three gaseous diffusion plants and the SRP production reactors).
- Conduct ongoing technology development and system R & D activities that focus on effectiveness of components, subsystems, and systems.
- Conduct jointly sponsored activities with utilities and industry to facilitate commercialization of technology.

These objectives for the total REAP program aim at the single overall goal of achieving optimum usage of available residual energy within the private sector. Specific objectives of the EAST Facility are: (6)

- Confirm performance specifications for equipment.
- Obtain reliable performance data for operating cost and investment predictions.
- Perform system application analyses.
- Compress testing time using statistical-engineering techniques.
- Determine mean time between failure of equipment and wearout times of hardware systems.

- Provide for dissemination of information to potential end users.
- Establish a reservoir of trained and experienced personnel available to assist end users in system installation, operation, and maintenance.

IV. REAP Elements Impacting EAST

The work breakdown structure for REAP is given in Figure IV-1. Four of the six level 3 elements in the figure have special bearing on the System Test and Evaluation Task and the EAST Facility. These four elements:

- Recovery of Residual Heat from DOE Production Facilities,
- Applied Technology Development,
- Waste Heat Recovery and Utilization Development, and
- Planning and Analysis

will therefore be discussed before summarizing the Systems Test and Evaluation Task.

A. Recovery of Residual Heat from DOE Production Facilities.

DOE is negotiating a contract with the Ohio Department of Energy to fund a study to use the Portsmouth Gaseous Diffusion Plant (GDP) waste heat at a planned nearby industrial park. The plan calls for use of the Central Energy Management System (CEMS) concept in which heat pumps, power generation systems, and direct-use options are optimally combined under a Central Energy Management System to best meet customer demands.

Candidates for the industrial park include a 50 million gallon per year ethanol plant, a one hundred thousand ton per year pulp plant, a seven thousand ton per year grain drying facility, a 12 million board-foot sawmill and a pharmaceutical preparation plant. As described in the Systems Analysis Report (1) the CEMS would utilize about 128,000 gallons/minute of residual hot water at the Portsmouth facility and would provide about 400 million Btu/hr of 300°F steam and 17 MW of electricity. Two heat pumps would be used, each with the capacity of 200

FIGURE IV-1
REAP WORK BREAKDOWN STRUCTURE

million Btu/hr. The electrical power would be generated by four 4.25 MW units. United Technologies Research Center is the subcontractor performing the CEMS work. The DOE cost for the first phase of the Portsmouth study is projected to be \$936,000.

DOE is also negotiating a contract with the E. M. Bailey Distributing Co. to study the use of the Paducah GDP residual heat to provide energy for a proposed 4 to 20 million gallon/year fuel-grade ethanol production plant. The 25,000 to 125,000 lbs/hr of 20 psi process steam required for the plant would be distributed by 1 to 4 four stage heat pumps. Mechanical Technology Inc. is the subcontractor responsible for the heat pump work. Vulcan of Cincinnati would be the architect engineer. The cost to DOE for the first phase of the Paducah study is projected as \$856,000.

Efforts are also underway to utilize the residual heat at the Oak Ridge GDP. A number of options are being considered including conversion of coal to methane with the process heat being supplied by a heat pump.

In addition to these studies, DOE is moving ahead with plans for a systems application evaluation at the Portsmouth GDP where a 600 gallon/year loop will be installed to heat a vocational school and to demonstrate agricultural greenhouse and lumber pre-drying applications. The evaluation will provide valuable experience with respect to solving the multi-faceted institutional problems surrounding waste heat utilization. Final design of the heat delivery system and greenhouse and lumber drying operations is scheduled for the end of fiscal year 1981.

B. Applied Technology Development

In 1978 six private contractors received awards under DOE's Program Research and Development Announcement, PRDA DPS-78-1, to perform R & D for absorption chillers and heat pumps. These awards which were equally split between these two categories may

result in systems testing at the EAST Facility. Specific systems requirements were not provided in the PRDA although the general temperature range of 150°F was given. H. G. Arnold of the Energy Division of Oak Ridge National Laboratory (ORNL) has overall responsibility for management of the PRDA projects.

B.1 Absorption Chillers

Horatio Perez-Blanco of ORNL has specific responsibility for managing the absorption chiller projects.

i. ITC/Solar Corporation (Malcom Frazier, Project Manager)

The principal thrust of the ITC/Solar effort is to develop more efficient absorption refrigeration from low temperature heat sources by developing and demonstrating conjugate cooling. The refrigerant and the conjugate cooling concept consist of two or more liquids which are miscible at lower temperatures (85°F) but become partially miscible at higher temperatures, e.g., 120°F. Liquid refrigerant is recovered by using the 150°F residual heat to separate the liquids but there is no phase change as in the conventional absorption systems. Design of a three-ton cooling system is scheduled for fiscal year 1981 with completion of construction and testing at ITC/Solar Corporation in fiscal year 1982.

ii. Foster-Miller Associates (Scott Hynek, Project Manager).

Foster-Miller is developing a vapor compression refrigeration system of 20-tons cooling capacity in which the compressor is driven by low-grade residual heat. Thermal activated compression is accomplished

by modifying a portion of the cylinders in the compressor to serve as an expander motor. The project is in the conceptual design stage with fabrication and testing planned for FY 1981 and FY 1982.

- iii. Battelle-Columbus Laboratories, (William T. Hanna, Project Manager)

This system under development by Battelle is perhaps the farthest along of the absorption chiller projects. Battelle has taken parts from a 100-ton commercial unit to assemble a system of 25 to 50 tons cooling capacity that will operate with heat sources below 150°F. The system relies on advanced desorbers for achieving the cooling effect. The initial design and testing of these desorbers started June 1, 1980. Verification and demonstration of the modified unit at Battelle is expected to be completed by August, 1981. The System Performance Summary for the Battelle unit is given in Table IV-1.

B.2 Heat Pumps

F. C. Chen of ORNL has specific responsibility for managing the heat pump projects. Only two of the three projects are described here. The contract for the third project which involves a closed cycle multi-stage freon heat pump driven by an ammonia Rankine bottoming cycle is still being negotiated.

- i. General Electric Company, Schenectady, New York (Heinze Jaster, Project Manager).

GE is developing an open cycle heat pump which utilizes three compressors with staged inter-cooling

TABLE IV-1

SYSTEM PERFORMANCE SUMMARY FOR BATTELLE UNIT

Residual Heat Source

Fluid	Water
Temperature in	60°C
Temperature out	44°C
Flow rate	5.8 kg/s

Heat Sink

Fluid	Water
Temperature in	19°C
Temperature out	23°C
Flow rate	33.6 kg/s

Cooling Effect

Fluid	Chilled water
Temperature in	13°C
Temperature out	4.5°C
Flow rate	4.92 kg/s

Chiller

Working fluid	Solution of Li-Br-water
Capacity	175 kW
COP	0.45
Parasitic power	5 kW
Package size	Maximum current 105 A L:W:H = 6.2 x 3.7 x 6.2 m

under the PRDA and with co-funding from the New York Energy Research and Development Administration. The capacity of the heat pump has yet to be finalized, but probably will be in the range 1000 to 5000 lbs/hr steam at 5 to 10 psig. Construction and testing will take place in FY 1982. GE plans to test parts of the system but they do not plan full-scale system testing. The unit will be demonstrated at an industrial site in New York State.

ii. Mechanical Technology Inc., (H. N. Leibowitz,
Project Manager)

MTI is developing an open-open TM Rankine heat pump which utilizes 1800 gallons/minute of 150°F water. The MTI system will deliver 5000 lbs/hr of 10 psig steam. The system has two distinguishing characteristics, the absence of heat exchangers and the generation of the steam product directly from the waste heat source. A multi-stage compressor train for the heat pump is used to maintain a vacuum in the flash tank and to boost the pressure of the system to the desired level. The open-open system is in the conceptual design stage for heat pump test set-up. A commercial system has yet to be designed. Detailed equipment specifications for the test set-up have not yet been made but sufficient analysis and design have been completed to identify the general properties of the system.

C. Waste Heat Recovery and Utilization Development

High temperature (200°F - 1000°F) energy recovery was added to the Residual Energy Applications Program in 1980. The objective is to encourage industry to use Rankine bottoming cycle systems to recover high temperature residual heat and convert it to useful electricity. To this end DOE is providing \$3 million in co-funding to industries over the next four years for in situ

demonstrations. In the arrangement, DOE initially pays the capital equipment costs and the company pays for the installation. If the unit performs successfully, the company is obliged in ensuing years to pay the government for the unit, not at its original development cost, but at the prevailing full-volume production price. William Thielbahr of the DOE Idaho Operations Office has overall responsibility for management of the high temperature program.

The units of the high temperature program range in size from a 200 kW unit developed by Bi-Phase Energy Systems to a 4 MW unit developed by Mechanical Technology Incorporated which is to be installed at a Pacific Gas and Electric Company site. Three diesel-exhaust-driven units developed by Sundstrand Energy Systems are now being demonstrated at utilities and a fourth is being installed on a natural gas fired kiln operated by a ceramic parts manufacturing company. It is anticipated an additional ten Sundstrand units will be demonstrated under the program.

The EAST Facility will augment this program by providing needed facilities for developmental testing plus, for manufacturers and potential users, well-documented results of exhaustive performance testing. (6) These activities will include not only high temperature bottoming cycles, but also industrial heat pumps and other commercially available heat recovery systems. In some cases equipment manufacturers need the EAST Facility for developmental testing because they do not have a waste heat source. Endurance testing is needed to study, among other things, the bearing life of single and multi-staged turbines or the possibility of air leaking to the working fluid.

D. Planning and Analysis

W. P. Teagan and J. C. Burke of Arthur D. Little Inc. have reviewed the status of the technology of the following REAP system components (15,16):

1. Low temperature power cycles.
2. Heat pumps.
3. Heat actuated cooling cycles.

In summary, they found that all the necessary technology for REAP systems is essentially in place or already under development and hence only a limited new development effort will be required. The single new development they recommended was modification of the heat pump cycle to use a wet expander in place of the throttle valve of conventional heat pumps. Their preliminary analysis indicates the wet expander, which is capable of doing work as the fluid passes from the condensor at high pressure to the evaporator at low pressure, could improve the economic performance of heat pumps by 15-25%.

The heat exchangers, pipes, fluids, and turbines of REAP low temperature power generation systems have considerable commonality with respect to temperature range capacity with on-going solar, low temperature geothermal, and OTEC programs and, hence, there are numerous firms with experience in these areas. Custom closed loop heat pump systems are available with output capacities of 25 million Btu/hr or more; these systems can operate at temperature levels of 220 to 250°F. There are on-going programs, for example, under PRDA DPS-78-1 and in the DOE Office of Industrial Programs, which are investigating open cycle configurations and improved working fluids to yield higher coefficients of performance and output temperatures up to 400°F.

Absorption cooling systems capable of operating at 180°F input temperature are now widely used in heat recovery applications. The only active programs to develop thermally activated cooling systems of the absorption or Rankine type which operate as low as 140°F are those sponsored by REAP as part of the PRDA.

V. Systems Test and Evaluation (FY 1980)

Work performed by the South Carolina Energy Research Institute during FY 1980 on the Systems Test and Evaluation Task was divided into four subtasks: Systems Analysis, Test and Operations, Environmental Analysis, and Support and Integration. The last of these subtasks is the subject of this report. The first three are extensively documented in References 1-5, and therefore will only be briefly summarized here. The Work Breakdown Structure for the Systems Test and Evaluation Task is given in Figure V-1.

Work during FY 1980 was directed at definition of the appropriate scope and capabilities of the EAST Facility and associated environmental and institutional issues. Plans were developed for the design, construction and operations of the facility and for addressing the relevant issues. Emphasis was on satisfying the testing requirements for the large-scale low temperature energy conversion systems needed for the Federal facilities. Subsequent work in FY 1981 under Contract DE-AC09-77ET-12866 will be directed at providing complete requirements for a core test facility that will not only enable developmental testing of large-scale energy conversion systems, but also confidence testing of moderately sized low and high temperature systems. The work scope for the requirements documentation is given in Appendix A.

A. Systems Analysis

The Systems Analysis effort (Reference 1) was directed primarily at obtaining a description of the systems which would best recover the residual energy at the Federal facilities. However, the applicability of these systems in the private sector was also considered. The Central Energy Management System (CEMS) approach which employs heat pumps and Rankine power systems for energy recovery and utilization was used. United Technologies Research Center, as subcontractor to ERI, had the major part in

FIGURE V-1 - CONTRACT WORK BREAKDOWN STRUCTURE

developing this approach. It was found that a CEMS located near a typical Federal gaseous diffusion plant could economically recover reject heat to provide the thermal and electrical requirements of a representative industrial park. For example, by utilizing the 128,000 gpm waste hot water stream from a selected building at the Portsmouth GDP and through careful system optimization, it is possible to provide, in a cost effective system, about 400×10^6 Btu/hr of 300°F steam as well as 17 MWe for use in an industrial park containing industries indigenous to the area. The actual thermal and electric output provided by the CEMS can be varied over a wide range and matched to the thermal and electric needs of the industrial park constituents. The optimum thermal and electric split would be a strong function of the prevailing fuel and electric energy costs and other site-specific factors.

The heat pump portion of the CEMS study in Reference 1 included:

- A review of the thermodynamic heat pump cycles. A Rankine cycle was selected as the only practical near-term approach for recovering waste heat.
- An examination of Rankine cycle heat pump configurations. Single fluid closed cycles, steam semi-open and open-cycles and dual-fluid cycles were identified for further study.
- An analysis of working fluids for flammability, toxicity, cost, critical temperature, thermal stability and minimum cycle pressure. Ten fluids were selected for study in the closed cycle systems.
- An examination of five prime movers: Gas turbines, diesels, steam turbines, electric motors and waste heat driven Rankine power systems. Gas turbines and diesels were selected for further analysis because their waste

heat can be recovered in the form of process heat at the same temperature levels required for industrial applications. Their overall performance would therefore be relatively high compared to steam turbine and electric motor drives.

- An evaluation of return-on-investment calculations using the Portsmouth GDP waste heat source and the thermal energy requirements of a hypothetical nearby industrial park. This evaluation considered various combinations of the selected drivers and heat pump configurations. A system was selected which showed the highest rate-of-return and other practical cost criteria.
- An analysis of five (5) private sector applications using the configuration developed for Portsmouth. The dual-fluid, closed cycle thermally driven heat pump system was shown to be applicable to these alternatives.

It was concluded from these heat pump studies that:

- Large capacity, heat-engine driven, dual-fluid Rankine cycle heat pumps can effectively provide industrial thermal process heat (300°F Steam) at attractive return-on-investment rates from low-temperature waste sources at Federal nuclear facilities and numerous base-load utilities.
 - a. Before tax, return-on-investments ranging from 29 to 36 percent are feasible with Rankine cycle heat pumps capable of providing 100 to 400 x 10⁶ Btu/hr of process steam at 300°F using 150°F hot water from the four Federal facilities for on-site applications.
 - b. If the heat pumps are located at nearby industrial parks, such as one considered in conjunction with the Portsmouth, Ohio, gaseous diffusion plant, the cost

of the mile and a half (1-1/2) pipelines in each direction will lower the before-tax, return-on-investment by about 6 percentage points for the large (100 to 400 x 10⁶ Btu/hr) capacity units.

- c. Since the residual heat from base-load utilities is generally available at some 40 to 50°F lower temperature than at the Federal facilities, the return-on-investment rates are reduced by about 10 percentage points and therefore any industrial parks or individual industries utilizing 300°F steam must be located essentially on-site. If lower output temperatures, i.e., 250°F, are suitable for the industrial applications, the large capacity heat pumps can provide before-tax, rate-of-returns above 30 percent.
- Residual heat normally available at 150 to 180°F from individual industrial plants can also be economically converted to 300°F thermal process steam by heat-engine driven heat pumps if the plant requires more than 50 x 10⁶ Btu/hr. As the available waste heat temperature decreases below 150°F, the output capacity of the heat pump must increase to 100 x 10⁶ Btu/hr to maintain a 20 percent or higher before-tax, return-on-investment.
- Large gas turbines and diesel engines (> 5000 HP) are the most effective heat engines for these applications since they are highly efficient and their residual heat can be efficiently used to supplement the heat pump output to provide industrial thermal process needs at 300°F and above. Smaller gas turbines and diesels are less attractive because they are less efficient and have higher specific costs. Electric motors are less acceptable because they do not permit recovery of the power generation source waste heat.

- All the components selected in the preferred heat pump configuration are classified as state-of-the-art. For this reason the development program envisioned on this particular equipment for the EAST Facility is system as opposed to component oriented. Future considerations and other manufacturers may include component oriented programs.
- By using a modular approach (100×10^6 Btu/hr/Module) to meeting the large waste heat flows, EAST Facility will be sized to test actual full scale modules which could then be combined with other modules and be installed at a waste heat source.

The power generation portion of the CEMS study in Reference 1 included an investigation of relevant thermodynamic aspects of low temperature power generation. This included a preliminary evaluation of the component sizes and performance for systems using various working fluids. Detailed sensitivity and trade-off studies were performed which addressed such aspects as pipeline optimization, benefits of multi-pressure evaporation cycles, effects of waste-stream temperature, condenser temperature and heat exchanger temperature differences. The study examined cooling water requirements, and also provided preliminary data on the design, cost and performance of a power recovery system at the Portsmouth GDP.

The study concluded that:

- Electric power can be generated economically with dual pressure Rankine cycle systems from the vast amounts of warm water (150°F) discharged by the Federal nuclear facilities.
- Ammonia is the preferred working fluid for these low temperature applications because of its superior heat transfer, thermodynamic and turbomachinery

characteristics relative to water and other organic fluids. In the 1 to 30 MWe size range, an ammonia system would be about 50 percent less costly than its nearest competitor -- an R500 dual-pressure-system.

- Ammonia is the preferred working fluid even if an isolation heat exchanger (IHE) is required in the Federal facility application and no IHE is installed when R500 is used. In this case the ammonia system would still be about 30 percent less costly.
- Up to 40 MWe can be recovered at each of the three gaseous diffusion plants (Oak Ridge, Portsmouth and Paducah), using ammonia multi-pressure systems.
- The same type of power recovery systems can be used for low-temperature industrial effluents with typical sizes in the 1-2 MWe range.
- The cost and power expenditure of a pipeline from the waste heat source to the power plant site can adversely affect the economics of power recovery. Therefore, power recovery systems must be located as near to the warm water source as possible.
- Multi-pressure Rankine cycle systems are thermodynamically superior to single-pressure systems. A dual-pressure system, for example, produces about 35 percent more output than a single-pressure system and is, therefore, less sensitive to the adverse economic impact of a pipeline.

Details concerning the heat pumps, power generation systems or CEMS can be obtained from the Reference 1 report.

B. Test and Operations

As indicated in the work breakdown structure in Figure V-1 the Test and Operations effort consisted of developing the scope and capabilities of the EAST Facility, preliminary policy, objectives and guidelines, and facility design and operating data. An initial look at the scope and capabilities of the EAST Facility was documented in the Reference 5 report. In addition to developing these concepts further, Reference 2, discusses relevant policy issues and presents preliminary design information regarding the physical plant and facility test and support equipment. Reference 2 also contains estimates of initial construction costs and staffing requirements for a two bay, three shift operation.

Some of the policies which were addressed in Reference 2 are:

- management responsibilities of test project participants and program managers,
- facility flexibility,
- test project sponsorship,
- test article ownership,
- test article damage and liability,
- safety,
- environmental protection,
- ranges of test conditions,
- facility growth,

- types of tests,
- test planning,
- priorities and schedules,
- test article readiness,
- test control,
- quality assurance and,
- test result reporting.

The preliminary design data developed for the EAST Facility was based on the large-scale prototype units in the Systems Analysis Report, viz., closed-cycle, dual-fluid heat pumps of 100 million Btu/hr capacity and 4.25 MWe power generation systems. The heat pump is driven by a gas turbine. EAST Facility requirements for testing the heat pump and power generation system are reproduced from the Test and Operations Report in Table V-1.

A first look at a possible layout for the EAST Facility has been developed based on the requirements in Table V-1. Drawings of the layout and site plan can be found in the Test and Operations Report. The core of the facility consists of one indoor test bay for heat pump systems, with a maximum input capacity of 10,000 gpm of hot water from the reactor effluent, and one outdoor test bay for electrical power generation systems, with a maximum input capacity of 22,500 gpm of hot water. Each bay was sized to accommodate one test system at a time. The electrical power generation system was placed on an outside concrete pad attached to the main building. The basic building is approximately 200 ft. by 200 ft. The site for the facility building was selected close to Par Pond to minimize the cost of

TABLE V-1
EAST FACILITY REQUIREMENTS

<u>Heated Water</u>	<u>Heat Pump System</u>	<u>Power Generation System</u>
Flow rate	10,000 GPM	22,500 GPM
Temperature	150 F	146 F
Source	"P" Reactor Coolant	"P" Reactor Coolant
Required Pressure	20 psig	15 psig
<u>Cooling Water</u>		
Flow rate		72,000 GPM
Temperature		60 F
Source		Par Pond
Required Pressure		5 psig
<u>Test Cell Specifications</u>		
Length	60 ft.	80 ft.
Width	40 ft.	40 ft.
Height	25 ft.	70 ft. **
Pit Depth	N/A	30 ft.
Crane Capacity*	5 tons	5 tons
<u>Additional Fluid Handling & Storage</u>		
	R11	
	No. 2 Fuel Oil	Ammonia
	Lubricating Oil	Lubricating Oil
<u>Electrical Power Required</u>		
	500 kW	600 kW
<u>Auxiliary Requirements</u>		
	Gas Turbine Control	Grid Connection
	Hot Water Control	(Induction Gen.)
	300°F Steam Dissipator	25 Tons Space Cooling
	G/T Exhaust Stack	Leak Detection
	(80,000 CFM @ 300°F)	
	125 Tons Space Cooling	
	Cooling Tower	

* Outside crane used to bring in large equipment

** No roof in this test cell area

supplying large amounts of cooling water (approximately 100,000 gpm) for the test equipment.

Provisions for engineering office space, shop area, control rooms, a means to temper the input hot water, flow distribution areas, and an electrical power room are included in the layout drawing. Facility expansion capabilities were specified and limited only to heat pump test bays, capable of accommodating full systems and/or limited component systems. Expansion was not provided for electrical power generation system testing due to the large size of this type of equipment and its large demand for cooling water. It was estimated it would cost approximately \$9.6 million dollars to build the facility. If the two bay facility were staffed for three shifts per day operation, 61 persons would be required, including professional, technical, and clerical personnel, but not including financial and legal staff support.

C. Environmental Analysis

To aid in the smooth and orderly siting of the EAST Facility, relevant environmental analyses have been conducted in parallel with the technological investigations. It is especially important that the environmental analysis program be an integral part of the EAST Facility design process. If knowledge of the natural resources to be used is brought in early in the planning process there should be little or no environmental impact that cannot be managed by the facility operators.

During this contracting period, ERI began two tasks. In the first task the generic environmental issues surrounding the utilization of waste heat, and the role that the EAST Facility could play in helping to develop criteria and methods for siting Central Energy Management Systems were examined. In the second task the environmental issues surrounding the siting of the EAST Facility on the Savannah River Plant were studied.

Based on our review of the Department of Energy guidelines for compliance with the National Environmental Policy Act of 1979, we concluded that a generic environmental assessment for the REAP program should be initiated as soon as possible. This review should include a discussion of the potential impacts of the operation of CEMS on the environment and the impacts of the operation of waste heat sources (such as power plants) on the siting and operation of CEMS.

Based on our general review of the environmental regulations, and the natural resources that the Savannah River Plant operates with, we concluded that important design criteria for siting the EAST Facility were to entirely confine all effects within the Savannah River Plant (SRP) boundaries and to only use SRP resources. If the facility is sited on Par Pond, we believe that there will be no significant effect of the EAST Facility on the environment as it is defined by existing Federal and State environmental regulations. There were several reasons for choosing the P reactor system and the Par Pond area at that time and several more have since been identified. They are completely within the boundaries of the SRP reservation, and as long as evaporation of cooling water is not significantly increased by the operation of the EAST Facility, no additional water need be drawn from the Savannah River. The EPA has recently required SRP to complete a study of the impact of withdrawing water from the Savannah River on the fish population in the river at considerable cost. There is a large body of information already accumulated on the Par Pond cooling system which would allow for a fairly sophisticated environmental analysis to be done. Should there be an accidental spill of toxic substances into the waste water stream, the effects would, in all probability, be confined to the Par Pond system. The Savannah River Plant site has been designated as a National Environmental Research Park, and there have been a large number of studies on the Par Pond system. It can be shown that further use of the cooling system would be an aid to understanding how industrial processes might effect the environment. To this end, ERI held several discussions with

investigators of the Savannah River Laboratory and Savannah River Ecology Laboratory on how the environmental analysis program for the EAST Facility might be coupled with the research programs of the laboratories. Both organizations have carried out significant research programs on the Par Pond system. It is important that these organizations be included throughout the siting program to alleviate any concerns they may develop about possible environmental impacts caused by the siting and operation of the EAST Facility.

VI. EAST Facility Mission

A. Amount of Residual Energy Available

As noted in Section II, the EAST Facility was born out of the need to provide test facilities for developmental testing of large-scale, advanced energy conversion systems for the Federal facilities. The goal has been to use the Federal facility applications as a springboard to transfer the technology to the private sector. We now also envision the EAST Facility as providing a direct link in the transfer of the technology from manufacturer to private sector user via varied types of confidence testing. This expansion in scope is most apparent in the Heat Recovery and Utilization Task of REAP (Figure IV-1 and discussion in Section IV.C). The following is a preliminary assessment of the role of EAST in accelerating market penetration.

Table VI-1 reflects our estimates of annual residual heat at the four DOE facilities and in the private sector. The numbers include only the more easily recovered forms of residual energy and do not include product heat losses. It is very difficult to obtain accurate numbers for reject heat nationally because individual plants in the same 4-digit Standard Industrial Classification (SIC) can vary greatly. There is plenty of room for refinement of these numbers, but as will be seen later, the penetration factor, the fraction of the residual energy that will ultimately be recovered, has even greater uncertainty.

B. Sizing of Heat Recovery Systems

Manufacturers developing equipment to recover the residual heat will seek to produce standardized units, since custom-made units are more expensive. Thus they will want to take advantage of possible cost reduction due to size scale-up and at the same time not oversize the unit for individual market applications. Cost advantages associated with size scale-up of heat pump

TABLE VI-1

ANNUAL RESIDUAL ENERGY
(10^{12} BTU/YEAR)

	TEMPERATURE OF RESIDUAL ENERGY			
	LIQUID			GASEOUS
	95 - 120°F	130 - 160°F	170 - 200°F	300 - 1000°F
FOUR DOE FACILITIES (1)		280		
INDUSTRY (1,17)	1100	1680	155	3710
UTILITIES				
o BASE-LOAD (1)				
(WET COOLING TOWERS)	2800			
o GAS TURBINE & INT. COMB. ENGINES (A)				70

- (A) 47,511 THOUSAND BARRELS OF OIL WERE CONSUMED BY GAS TURBINES AND INTERNAL COMBUSTION ENGINES IN 1978 (18).
APPROXIMATELY 44% AND 16% OF GAS TURBINE AND DIESEL FUEL CAN BE RECOVERED AS WASTE HEAT ABOVE 300°F (1).

systems are illustrated in Figure VI-1 from Reference 1. Specific costs depend among other things on input temperature, temperature lift, number of compression stages and type of cycle, e.g., open or closed. The numbers in Figure VI-1 are for a waste heat stream inlet temperature of 150°F and output steam of 67 psia (300°F saturated). The assumptions of the ROI calculation are given in Table VI-2. Sizes of the units to meet market demand were estimated in the residual heat resource/applications analyses in Reference 1. The results are summarized in Table VI-3. It is preferable to utilize the residual heat at its origin, rather than suffer the institutional problems associated with arranging one or more industries to use another's residual energy. The Reference 1 study indicated that heat pumps providing 10 million Btu/hr of 250°F saturated steam would meet process heat requirements for most plants having waste streams in the temperature range 95°F to 120°F. However of these industries there are some (e.g., meatpacking, fluid milk, wet corn milling, pulp and paper mills, alkalies and chlorine, inorganic pigments, noncellulosic fibers, cyclic crudes and intermediates and phosphor fertilizers) large enough to require over 100 million Btu/hr of steam. Process heat requirements for industries with residual heat in the range of 130°F to 160°F could be satisfied with single or multiple heat pump units which deliver 30 million Btu/hr of 250°F to 300°F saturated steam. A unit which provides 100 million Btu/hr of 250°F to 350°F saturated steam from the 170°F to 200°F sources would satisfy most potential applications here.

Larger units, in the range of 100 million to 200 million Btu/hr, which take maximum credit for size scale-up, appear most suitable for recovering the large quantities of residual heat from the DOE facilities and the base-load utilities. (1) Utilization of these large quantities of residual heat via heat pump technology is not an easy matter however because it requires siting of an industrial park nearby and this is a slow and difficult task.

FIGURE VI-1

HEAT PUMP SYSTEM ECONOMICS FOR PORTSMOUTH APPLICATION

TABLE VI-2
ASSUMPTIONS USED IN HEAT PUMP ECONOMIC ANALYSIS

System Life	20 years
Depreciation Period*	16 years
Investment Tax Credit*	10%
Misc. Annual Charges	2%
O & M as Percent of Capital Cost	2.25%
Capital Cost Year	1980
Cost Year of Fuel, Electricity, etc.	1980
Start-up Year	1982
General Inflation Rate	6%
Escalation Rate of Fuel**	4%
Escalation Rate of Electricity**	2%
Cost of Fuel	\$3/10 ⁶ Btu
Cost of Electricity	3.3¢/kWhr
Depreciation Method*	Straight Line
Tax Rate*	48%
Discount Rate	10%
Operating Time Per Year	8000 Hrs.

* These Items are Omitted for Before Tax Calculation

** Above General Inflation Rate

TABLE VI-3. ESTIMATED HEAT PUMP/POWER GENERATIONS SYSTEM SIZES

	HEAT PUMP CAPACITY (10^6 BTU/HR)			POWER SYSTEM CAPACITY (MWE)		
	<u>95-120°F</u>	<u>130-160°F</u>	<u>170-200°F</u>	<u>130-160°F</u>	<u>170-200°F</u>	<u>300-1000°F</u>
DOE FACILITIES		100-200		4-5		
INDUSTRY	10-30 (.50)	30 (.50)	100 (.30)		1-2 (.30)	1-2 (.60)
UTILITIES	100-200 (.20)					1-2 (.60)

NOTE: ESTIMATED MARKET PENETRATION FACTORS ARE GIVEN IN PARENTHESES.

The cost per kW_e output of power generation systems is principally dependent on the waste stream temperature and the overall capacity of the system. These dependencies are illustrated in Figures VI-2 and VI-3. The shapes in Figures VI-2 and VI-3 were developed from Reference 15. Costs were normalized at 150°F and 17 MWe to the ammonia system without an intermediate heat exchanger proposed for Portsmouth in Reference 1. The cost vs. temperature relationship is primarily governed by the thermodynamic efficiency of the cycle. Higher temperature systems typically yield greater paybacks. At the lower temperatures more heat exchanger surface and large turbomachinery is required. It can be seen that over the output range 2-30 MW, the unit cost is a very weak function of size. This is a result of the weak dependence of the unit cost of the heat exchangers in this limited output range. Stronger dependence on size may be observed if there is a site preparation cost that depends only weakly on the size of the system.

Our studies indicate that most low and high temperature waste heat Rankine cycle power generation applications in the private sector can be satisfied by 1-2 MW capacity units. For the special applications at the DOE facilities there appear to be cost advantages to use multiple 4-5MW systems for the reasons given in Reference 1.

C. Potential Market

To derive the number and size of the industrial heat pumps and power generation systems likely to be in use over the next two to three decades it is necessary to estimate ultimate penetration of the technology into the marketplace. This is obviously very difficult to do because it depends on the performance of the equipment, the perceived merit of the equipment by industry, Middle East factors, etc. Our guesses at the penetration factors are included in Table VI-3. They could be in error a factor of three or more. Our projection for the number and sizes of the systems assuming the Table VI-3

FIGURE VI-2
EFFECT OF WASTE STREAM
TEMPERATURE ON INSTALLED COST
OF POWER GENERATION SYSTEMS

FIGURE VI-3
EFFECT OF SYSTEM SIZE ON INSTALLED
COST OF POWER GENERATION SYSTEMS

penetrations is given in Table VI-4. Additional assumptions used in estimating the number of units are given in Table VI-5. The heat pump outputs assume a gas turbine driver, and take credit for recovery of exhaust heat from the turbine. (1)

From the above it is estimated that heat pumps in the year 2000 could be generating 780×10^{12} Btu/year of steam and Rankine cycle power generating systems could be generating 130×10^{12} Btu/year of electricity. The heat pumps would consume about 600×10^{12} Btu/year assuming a COP of 3 and that the compressor is driven by a gas turbine. To generate the steam with conventional boilers which have 80% efficiency would require 975×10^{12} Btu. Thus the fuel savings from heat pumps would be 375×10^{12} Btu/year. Electrically driven heat pumps would save only 40% of this amount if power plant efficiencies are taken into account. (1) Assuming the electricity generated by the Rankine cycle systems replaces electricity that would have been supplied from a conventional powerplant which is 33% efficient, the annual energy savings from the Rankine cycle systems would be 390×10^{12} Btu. Thus the energy savings from each of the technologies is very comparable and in combination would amount to 765×10^{12} Btu per year. The installed heat pump equipment in Table VI-4 would be worth approximately \$4 billion (1980), about 60% of this in the 10-30 million Btu/hr size range, the remaining 40% in the 100-200 million Btu/hr range.* The installed power generation equipment would be worth approximately \$1.2 billion (1980), all but 2-3% being high temperature bottoming cycles.

* \$50,000/ 10^6 Btu/hr output was assumed in this estimate.

TABLE VI-4. NUMBER OF UNITS IN USE IN PRIVATE SECTOR, YEAR 2000
(ASSUMING PENETRATION FACTORS OF TABLE VI-3)

TYPE UNIT AND SIZE RANGE	TEMPERATURE OF RESIDUAL ENERGY				TOTAL
	<u>95-120°F</u>	<u>130-160°F</u>	<u>170-200°F</u>	<u>300-1000°F</u>	
HEAT PUMPS					
o 10-30 x 10 ⁶ BTU/HR	1600	850			2450
o 100-200 x 10 ⁶ BTU/HR	200		10		210
POWER GEN. SYSTEMS					
o 1-2 MW			20	1600	1620

TABLE VI-5
ASSUMPTIONS USED IN ESTIMATING NUMBER OF UNITS

Heat Pumps

- Reduce temperature of input waste stream by 10°F. Heat pumps in series were not considered.
- Heat pump energy output = twice energy extracted from stream (approximate).

Power Generation

- 170°F - 200°F liquid streams: Reduce temperature of input stream by 40°F. Cycle efficiency = .06.
- 300°F - 1000°F gaseous streams: Reduce temperature of gaseous stream to 300°F. Cycle efficiencies range between .20 and .30.

D. Developmental and Confidence Testing

Keeping in mind the ultimate goal of REAP is to stimulate utilization of residual energy in and by the private sector, we have concluded from the numbers in Table VI-4 and separate discussions with equipment developers that the EAST Facility should provide not only for developmental testing of large-scale units, but also for confidence testing of smaller units. From Table VI-3 it can be seen that the heat pump sizes most suitable for the Federal facilities are comparable only with the sizes appropriate for the base-load utilities. It will take years to achieve a demonstration of heat pumps in these cases due to the major institutional problems associated with establishing a nearby industrial park. Smaller scale demonstrations would be easier to arrange. The large scale power generation systems proposed for the Federal facilities do not suffer from the time delays associated with the heat pumps because the electricity is in immediate demand, but their impact on the private sector is estimated to be relatively small (Table VI-4).

These considerations suggest that EAST in the near term address small capacity units, 10-25 million Btu/hr heat pumps and 1-2 MW power generation systems, to better stimulate penetration into the private sector. The large quantities of residual energy at the Federal facilities should be fully utilized in its own right as well as to advance usage at the utilities, but this is viewed as a later series of tests at EAST. These tests will be developmental in nature because only the components and not the complete systems exist.

The primary role of EAST in testing the smaller units will be to provide confidence testing to accelerate acceptance of the equipment by industry. This acceleration could result in significant energy savings as illustrated below. As evidenced in the Systems Analysis Report (1) paybacks on low temperature energy recovery systems are becoming more competitive with other energy options. The proposed Central Energy Management System

for Portsmouth produces 400 million Btu/hr of steam and 17 MW of electricity with a before tax rate of return in excess of 28 percent and would have a payback period of less than 4 1/2 years. High temperature bottoming cycles can have shorter paybacks because of better thermodynamic efficiencies.

Several equipment manufacturers have told us, however, that potential customers remain reluctant to purchase because of lack of operating history and concern the units may not be sufficiently reliable. The various types of confidence tests, including accelerated life testing, planned for the EAST Facility are discussed in the Test and Operations Report (2).

E. Equipment Developer/Manufacturer Input

Several equipment developers and manufacturers have been contacted by telephone or visited to brief them on the proposed scope and capabilities of the EAST Facility and obtain feedback from them.

E.1 Mechanical Technologies, Inc.

Low and high temperature power generation systems and industrial heat pumps are major development lines of MTI. Serving as a subcontractor they have assisted ERI in developing policy, objectives and guidelines for the EAST Facility and they are now assisting ERI in developing the physical requirements of the facility. As noted in Section IV, they are also heavily involved in other elements of REAP.

MTI has been a strong proponent of the need for a large scale, multi-purpose test facility, especially to perform confidence testing. They view the facility as filling the gap between the relatively limited testing of manufacturers and the more extensive testing required to give the user community confidence in the equipment.

F. J. McCrosson of ERI and D. R. Muhlbaier of DuPont, Savannah River Plant toured the facilities at Malta, New York, where MTI performs their equipment tests using a boiler to simulate the waste heat stream. A flow diagram of the Malta Test Facility is given in Figure VI-4. Their fuel costs average \$300 per hour of operation. The cost of simulating the waste stream thus makes long-term testing impractical.

E.2 United Technologies Research Center

UTRC assisted ERI in the conceptual design of large-scale heat recovery systems for the Savannah River Plant under the Reference 7 study, and has assisted us in the conceptual design of the Portsmouth Facility under the present study. In working with ERI they have stressed the economic importance of utilizing the size scale-up advantage of large heat recovery systems at the Federal facilities and base-load utilities. Although the components for these large scale systems are found in other applications, the proposed systems have never been assembled or optimized. There are no test facilities in this country large enough to perform the necessary systems tests. The EAST Facility would fill this need.

E.3 Battelle-Columbus Laboratories

D. R. Muhlbaier and F. J. McCrosson visited Battelle-Columbus Laboratories June, 1980 and discussed the EAST Facility with W. T. Hanna and W. H. Wilkinson.

Battelle is developing a 25-ton absorption chiller under PRDA DPS-78-1. They can do their own in-house testing for this size, but see industrial applications for units 10 times larger. They do not have the capability to test these larger units and therefore see a need for the EAST Facility. Hanna and Wilkinson said third party testing by a non-manufacturer would add considerable credibility to the test results. Battelle is also

FIGURE VI-4

Flow Diagram MTI-Malta Test Facility

interested in using EAST to test the Battelle Temperature Booster heat pump which they are developing.

E.4 Westinghouse Templifier Division

D. R. Muhlbaier and F. J. McCrosson visited R. C. Niess, J.G. Johnson and J. L. Ridings of the Westinghouse Templifier plant in Staunton, Virginia on September 26, 1980.

Westinghouse, along with Carrier, Trane, and York, have extensive industrial heat pumps manufacturing capabilities and substantial test capabilities. It would be expected these firms would be less interested in a government owned test facility than would be emerging equipment developers, and this expectation was borne out in our discussions.

Templifier heat pumps use electrically driven centrifugal compressors and provide hot water up to about 200°F. Units with capacities less than one million Btu/hr output are essentially off-the-shelf items and can be delivered within 6-8 weeks. The larger units, up to 25 million Btu/hr, are frequently custom-made and it may take between 20 and 50 weeks to deliver one of these units. All Templifier manufacturing is performed under one roof in an area of approximately 600,000 sq. ft. The test area is about 70 feet square and 50 feet high. They do some stress testing at Staunton but rely mostly on the results of field testing to evaluate performance. Each centrifugal unit is tested 8 to 16 hours in the facility at the customer's conditions. The operation is fairly simple in terms of requirements because they do not need a waste heat source. They utilize the heat output from the heat pump in combination with a cooling tower to provide the input conditions that are needed. They have three test blocks: one at 500 ton capacity, another at 800 tons and the largest with a 1,000 ton capacity. They have the ability on this largest block to test the compressor alone using a hot gas by-pass and can regulate the tip speed with an eddy current clutch.

Technology development is conducted at the Westinghouse R & D Center in Monroeville, Pennsylvania. The main thrust of this effort is to achieve higher output temperatures (300°F - 400°F) using new refrigerants.

They had not yet found a market for units larger than 25 million Btu/hr, but suspected that such a market would probably develop in the future. They said that they would use the EAST Facility to test these larger units rather than expand their own test capabilities.

From our discussions it was clear the Westinghouse people do not see a particular need for confidence testing at the EAST Facility and that their preference is to build confidence by means of demonstrations in the industrial environment. They are not only confronted with questions regarding reliability but frequently also mediocre payback periods, and the EAST Facility does not address this matter. From our viewpoint the EAST Facility more thoroughly addresses the questions of reliability than demonstrations do, but the EAST Facility should be considered as complementing rather than replacing demonstration programs.

E.5 Thermo-Electron Company

Thermo-Electron has developed a 440 kw high temperature bottoming cycle which uses Fluorinol-85, and an open system heat pump which uses a rotary screw compressor. Ravi K. Sukhuja of Thermo-Electron was contacted in June, 1980 for his comments on the EAST Facility. He was very interested in the EAST Facility because Thermo-Electron does not have facilities with adequate waste heat simulation. He said developers like themselves would all wish to use EAST for developmental and confidence testing.

E.6 General Electric Company

GE is developing an open cycle heat pump under PRDA DPS-78-1 with co-funding from New York ERDA. Sizes and flow rates are to be determined in the next two to three months.

GE does not have capability for systems testing of industrial scale heat recovery systems. In a telephone conversation with Warren Bessler in June 1980, he indicated to F. J. McCrosson that GE would probably wish to utilize the EAST Facility for developmental and confidence testing.

F. Timing

Figure VI-5 illustrates the critical points associated with growth of energy conversion technology. The earliest years are characterized by slow growth rate. The reason for the current slow growth rate for heat recovery equipment is lack of operating experience, as was noted in the study of industrial markets for organic Rankine cycle systems by Resource Planning Associates. (19)

At some point, denoted by A in Figure VI-5, the purchasing public gains sufficient familiarity with the equipment to make a decision whether or not to purchase, and when they should purchase. If the technology has proven itself, its growth rate will increase sharply after A. If the technology has acquired a poor reputation, growth will be curtailed for a long time even if deficiencies are remedied. This characteristic, that some buyers are innovators but the vast majority are imitators and must be shown, has been observed in numerous historical market penetrations of similar technologies. (20)

At point B the growth rate decreases and the number of new units entering the marketplace becomes essentially constant from year to year. This occurs when the total number of units in use is about equal to the projected steady-state production rate.

FIGURE VI-5

GROWTH OF ENERGY CONVERSION TECHNOLOGY

The annual steady-state production rate is computed such that the time between points B and C is equal to the lifetime of a typical unit. The point C denotes when ultimate penetration of the market is achieved. If the production capacity of the manufacturing sector did not level off at B, supply would soon exceed demand. After point C the annual production goes to replacement of old units.

This much simplified scenario serves to illustrate the importance of early operation of the EAST Facility and provides some insight into what might be considered an appropriate volume of testing each year. Figure VI-6 illustrates differences in the growth of the technology with and without the EAST Facility. In developing the EAST Facility curve in Figure VI-6 it was assumed the Facility began operation at the origin of the time scale and would test about the same number of units each year as would have entered the marketplace without the EAST Facility (solid curve in Figure VI-6). The tested units go to buyers who would not have otherwise purchased them. This alone would double the growth rate between the origin and point A. However, there are compounding effects which enhance the growth rate further. For example, the introduction of these new units into the marketplace will stimulate some additional growth because of limited increased visibility. Analogous increases in growth rate are built into the curve without EAST. More importantly, the general availability of documented test results will accelerate familiarity with the equipment by getting performance data into a greater number of hands sooner. Consequently point A is reached significantly sooner with the EAST Facility.

After point A, the impact of continued operation of EAST on accelerated technology transfer diminishes significantly. Instead the rapid growth rate between points A and B becomes the driving force. When point A is reached it is assumed the role of EAST will shift more to technology development aimed at expanding the market by recovering a greater share of the residual energy and perhaps also by increasing the penetration factor. The rise

FIGURE VI-6
ILLUSTRATION OF IMPACT OF TEST FACILITY
ON GROWTH RATE

between A and B in the figures is only illustrative. It will depend on the relative effectiveness (price, quality, environmental impact) of the heat recovery units compared to other process alternatives.

The growth curves in Figure VI-6 assume no major technological shortcomings emerge over the anticipated lifetime of the systems. Should such problems emerge, EAST would uncover them earlier and aid in their more rapid resolution. Much longer delays in penetrating the market would occur if the buying public discovered these problems on their own and the technology acquired a poor reputation.

Well-placed demonstrations in the industrial sector, as well as independent test facilities, can accelerate penetration. Sometimes only one or the other approach is necessary. Frequently, however, they both are needed to complement each other. The success of the penetration acceleration program will depend on the number of questions of the buyer that are answered. Demonstrations at specific plant sites provide real world performance data that is very important to the buyer. If the technology is relatively simple a demonstration may be all that is needed. If, as is the case in energy conversion, the equipment is complex, a handful of demonstrations may not be able to address many questions of the potential buyer. The conditions at his plant are probably different than at the demonstration site, and differences in operating requirements, temperature of the working fluids, pressures, and compressor tip speeds may bear significantly on performance and life of the systems in his application. We anticipate the potential heat pump buyer will frequently be more resolute than the bottoming cycle buyer in getting all the questions answered before entering into a purchasing agreement because his process may not have adequate steam back-up in the event of a heat pump outage.

Shortening the time to reach point A has a significant effect on the energy saved, primarily because of the rapid rise of the curves between points A and B. The above scenarios can be cast in analytical form to estimate this energy savings; viz.,

$$(1) \quad \frac{dU(t)}{dt} = \alpha U(t) \quad t_a < t < t_b$$

and

$$\frac{dU(t)}{dt} = B \quad t_b < t < t_c$$

where $U(t)$ denotes the total number of units in use at time t . The number of units in use at the critical points is denoted by A, B, and C, respectively:

$$(2) \quad \begin{aligned} U(t_a) &= A, \\ U(t_b) &= B, \\ \text{and } U(t_c) &= C. \end{aligned}$$

The parameter α regulates the sharpness of the exponential rise of $U(t)$ in the interval (t_a, t_b) . Values for α will be assigned later in the discussion. The energy saved by operation of the EAST Facility for τ years is:

$$(3) \quad S(\tau) = \gamma \int_{t_a}^{\tau} \Delta u \, dt \quad t_a < \tau < t'_c$$

where $\Delta u(t)$ is the difference in the number of units at time t because of EAST,

$$(4) \quad \Delta u(t) = \begin{cases} Ae^{\alpha(t-t'_a)} - Ae^{\alpha(t-t_a)} & t_a < t < t'_b \\ B[(t-t'_b)+1] - Ae^{\alpha(t-t_a)} & t'_b < t < t_b \\ B(t_b-t'_b) & t_b < t < t'_c \end{cases}$$

and t'_a , t'_b and t'_c denote the shortened time to reach the critical points A, B and C because of EAST. In Eq. (3), γ is the energy saved per heat recovery unit per year. We have ignored the relatively small energy savings gained over the period $t < t_a$.

The curves in Fig. VI-7 show the large impact the EAST Facility can have by shortening the time to reach the critical point A by only 1/2 year to 1 year. In generating these curves it was assumed:

$$C = 4280 \quad (\text{From Table VI-4})$$

$$\gamma = \frac{765 \times 10^{12} \text{ Btu/yr}}{4280} = 1.8 \times 10^{11} \text{ Btu/unit-yr.}$$

and

$$(t_c - t_b) = 15 \text{ years, the assumed lifetime of the heat recovery units}$$

From Eq. (1),

$$C = B [(t_c - t_b) + 1]$$

Therefore,

$$B = 267.5, \text{ the number of units produced annually when the market is in equilibrium.}$$

The parameter α was set by selecting the values for the difference $t_b - t_a$ that are shown in the figure:

$$\alpha = \ln (B/A) / (t_b - t_a)$$

A was assumed to be 20% of B (i.e., 53 units) and $t_a = 5$ years; however, the curves in Figure VI-7 are insensitive to these selections. The value of A does have a bearing on the capacity of the EAST Facility because it is the upper limit of the number of units that need to be tested over the time interval $(0, t_a)$.

FIGURE VI-7
ENERGY SAVED BECAUSE OF EAST FACILITY

The lower endpoint of the curves in Figure VI-7 corresponds to $t = t'_a$ and the upper endpoint to $\tau = t_c$. Additional energy savings do not occur beyond t_c because older units must now be replaced. The net energy savings from EAST, $S(t_c)$ is very well approximated by:

$$S(t_c) \approx \gamma C (t_a - t'_a) = \gamma C (t_c - t'_c)$$

Thus, the net energy savings due to EAST is equal to the annual energy savings from the energy conversion units at maximum penetration times the decrease in the time required to reach this penetration. As shown in Figure VI-7 a decrease of only one year yields a net savings of .8 quads. A two year reduction would double the energy savings.

The monetary value of the energy saved by EAST is 70 times the cost of the facility if:

- The EAST Facility reduces the time to reach maximum penetration by 1 year.
- The cost to construct and operate the facility over the five years interval $t < t_a$ is \$35 million (see Section VII), and
- The value of the energy saved is \$3/million Btu.

Referring back to Section VI-C where it was estimated the installed heat pump and power generation equipment at full penetration would be worth \$5.2 billion (1980), it can be estimated that annual business at equilibrium (267.5 units) would be worth \$325 million (1980).

G. Conclusions

- In the year 2000, industrial-scale heat pumps could be saving .4 quad per year. Rankine cycle power generating systems could save a similar amount.
- The EAST Facility will yield the greatest energy savings nationwide by providing early capability for testing heat pumps with output capacities of 10-30 million Btu/hr and high temperature bottoming cycles with outputs of 1-2 MW. Units with these capacities have the broadest immediate application. Heat pumps in the 100-200 million Btu/hr range experience inherent delays due to the need to establish industrial parks to utilize the steam output. The large power generation systems in the 4-5 MW range probably find application only at the Federal facilities. The EAST Facility should provide developmental testing capabilities for these larger power generation systems and heat pumps in later phases of testing.
- Early design and construction of the EAST Facility maximizes return on investment. Each year shortened by EAST from the time to achieve full penetration saves .8 quads.
- Sales of heat pump and power generation systems will total about \$325 million (1980) annually.

VII. Systems Test and Evaluation Plan, FY 1981 to FY 1988

The conclusions of the previous section are based largely on the industrial waste heat data contained in Table IV-1. Although it is desirable to confirm this data and obtain a better determination of the penetration factors, it is not likely these investigations would significantly alter the conclusions. The plans presented in this section for the design, construction and operation of the EAST Facility therefore aim at early testing of 10-30 million Btu/hr heat pumps and 1-2 MW high temperature bottoming cycles.

Provision for testing low temperature Rankine cycles in the 1-2 MW range and 50-100 ton absorption chillers are included in the initial (core) EAST Facility but these capabilities have lower priority because their impact on ultimate energy savings is less.

Two plans are considered in detail. The first is analagous to the July 1980 REAP Plan. (6) The second plan has the additional advantage of providing increased test capacity earlier and hence more rapid technology transfer. Facility costs in the early years are increased by this approach but the increase is small compared to the expected energy savings it would provide.

A. Plan 1

The overall schedule for Plan 1 is given in Figure VII-1. Costs are given in Table VII-1. These are estimated contractor costs for the periods indicated, and should not be confused with the budget authorization needed to carry out the program.

FIGURE VII-1 EAST FACILITY SCHEDULE - PLAN 1

TABLE VII-1
EAST FACILITY COSTS - PLAN 1
(THOUSANDS OF 1980 DOLLARS)

	FY 81	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	FY 88
CORE FACILITY								
DESIGN & CONSTRUCTION	1000	3500	3500	1600				
PRE-TEST OPERATIONS			150	1900				
FIRST TEST SERIES								
FABRICATION & INSTALLATION			1045	1045				
TESTING					3600			
FACILITY EXPANSION								
DESIGN & CONSTRUCTION				1000	2000	2000		
SECOND TEST SERIES								
FABRICATION & INSTALLATION					2635	2635		
TESTING						3900	3900	
THIRD TEST SERIES								
FABRICATION & INSTALLATION						6000	8000	2000
TESTING								3900
TEST EVALUATION, PLANNING & ANALYSIS	400	400	400	400	400	400	400	400
TOTAL	1400	3900	5095	5945	8635	14935	12300	6300

A.1 Core Facility

The timing for design and construction of the initial (core) EAST Facility is based on discussions with E. I. duPont de Nemours & Co., the probable design and construction contractor.*

The South Carolina Energy Research Institute will provide basic facility requirements by January 15, 1981 and amendments to these requirements based on additional discussions with heat recovery equipment manufacturers by March 16, 1981. The design task performed by the architect engineer (DuPont) includes preparation of the Technical Data Summary (TDS), as well as conceptual and final design. Preparation of the TDS will begin in November and end April, 1981. This effort involves melding local requirements as might pertain to offices, shops, environment and safety and power and grid control to the Facility requirements.

Conceptual design will start January 1981 and end April 1981. The objective is to provide a detailed job estimate at $\pm 10\%$ accuracy. This requires preliminary design which will furnish layouts (power and process) process schematics, major equipment lists, H and V schematics, C and A scope, and electrical and instrument diagrams (sub-stations and supply). Detailed cost estimates for design and construction will be furnished by June 1981. Design review and iteration will take place during July and August. Final design will begin in September 1981 and end May 1982. Eighteen months have been scheduled for construction. However, in our discussions with DuPont they indicated that twelve months would probably be enough. The turnover activity follows construction and involves acceptance of the Facility by the operating department which is the final authority on whether the Facility meets the original specifications.

*Discussions with J. P. Morin and D. R. Muhlbaier of DuPont at the Savannah River Plant, August 22, 1980.

In the Test and Operations Report (2) a cost estimate of 9.6 million dollars was given for a core facility with 2 large capacity test bays. One inside test bay was capable of testing heat pumps with outputs up to 100 million Btu/hr. The Facility design included four quick recovery boilers to provide back-up heat for the heat pump test bay. The second bay was outside the Facility and was capable of testing power generation systems up to 5 MW. Although the core facility is likely to be smaller, the 9.6 million dollar cost estimate is used in this plan because the cost is less sensitive to the size of the bays than to the costs of the heated water and cooling water piping (\$4 million). It may be cost effective, for example, to install the larger water distribution systems at the beginning in anticipation of Facility expansion later. Also, these costs assume the Facility is located near Par Pond and could change considerably if the Facility were located elsewhere. We assume the core facility will not initially have the hot water back-up system which was included in the Reference 2 cost estimate but the associated cost reduction is offset by the need to include a high temperature testing capability which was omitted from the original estimate.

A.2 First Test Series

Initially the EAST Facility will be capable of testing one heat pump, one high-temperature bottoming cycle, one low-temperature power generation system and an absorption chiller. A description of the units including costs is given in Table VII-2. Each of these systems could be fabricated in time to meet the schedule in Figure VII-1. Testing would span about 1 year. EAST Facility operating costs for the first test series and also for subsequent years are given in Table VII-3.

Table VII-2. EQUIPMENT SPECIFICATIONS AND COSTS*

FIRST TEST SERIES

I. Low Temperature Power Generation System

Capacity	1 MW
Residual Heat Source	
Fluid	Water
Temperature in	150°F
Flow rate	8,000 gpm
Heat Sink	
Fluid	Water
Temperature in	70°F
Flow rate	25,000 gpm
Package Size	L:W:H = 30:25:25 ft.
Installed Cost for testing at EAST	
@ \$1350/kw	\$1.35 million

II. Heat Pump

Capacity	10 million Btu/hr. at 220°F
Residual Heat Source	
Fluid	Water
Temperature in	150°F
Flow rate	1200 gpm
Prime Mover	1000-1300 horsepower
Package Size	L:W:H = 20:5:10 ft.
Installed Cost for testing at EAST	
@\$35,000/10 ⁶ Btu/hr.	\$350,000

* 1980 dollars

Table VII-2 (Continued)

III. High Temperature Power Generation System

Capacity	600 kw
Residual Heat Source	Exhaust from 10 MW Diesel or Gas Turbine
Package Size	L:W:H = 35:30:30 ft. (excluding cooling tower boiler and hot gas duct assembly)
Installed Cost for testing at EAST @ \$600/kw	\$360,000.

IV. Absorption Chiller

Capacity	50 tons cooling
Residual Heat Source	
Fluid	Water
Temperature in	150°F
Flow rate	100 gpm
Heat Sink	
Fluid	Water
Temperature in	70°F
Flow rate	600 gpm
Package Size	L:W:H = 20:12:20 ft.
Installed cost for testing at EAST @ \$600/ton	\$30,000

TABLE VII-3

COSTS FOR EAST FACILITY TEST OPERATIONS^D
(THOUSANDS OF 1980 DOLLARS)

	<u>FY 83</u>	<u>FY 84</u>	<u>FY 85</u>	<u>FY 86</u>
EAST STAFF	200	1000	1500	1750
PRIME CONTRACTOR (ERI/DUPONT)	200	500	700	750
SUBCONTRACTOR (STUDIES/SERVICES)		150	200	200
EQUIPMENT (MAINT/RPR/REPLACEMENT)		100	400	500
TECHNOLOGY DEVELOPMENT		150	400	500
OTHER	100 ^A	190 ^B	440 ^{B,C}	210 ^B
CONTINGENCY (10%)	50	210	360	390
	<u>550</u>	<u>2300</u>	<u>4000</u>	<u>4300</u>
TOTAL				

NOTES:

- A. INCLUDES INITIAL SUPPLIES (ADMIN, TECHNICAL, COMPUTER) PLUS HAND TOOLS AND SMALL EQUIPMENTS NOT TO BE PROCURED DURING INITIAL OUTFITTING OF EAST FACILITY.
- B. INCLUDES CONTRACTED FACILITY MAINTENANCE, LEGAL AND FINANCIAL SERVICES, SUPPLIES (ADMINISTRATIVE, PROCESS, DRAFTING, SHOP, OTHER), TRAVEL, UTILITIES, TELEPHONE, SHIPPING, PRINTING, PUBLICATIONS, PHOTOGRAPHY, OTHER ADMIN SERVICES.
- C. INCLUDES MANAGEMENT REVIEW IN 2ND YEAR OF OPERATIONS.
- D. NOT INCLUDED ARE SOME TEST PROGRAM COSTS THAT WILL BE BILLED TO CUSTOMER (DEVELOPER TEST SUPPORT TEAM, FACILITY MODIFICATION/DEMODIFICATION FOR SPECIFIC TEST, SPECIAL TEST REQUIREMENTS, ETC.). EVENTUALLY, SOME OF THE DEPICTED COSTS (PERHAPS 30%) WILL BE BORNE BY CUSTOMERS. IT IS TOO EARLY TO PROJECT EXPECTATIONS.

A.3 Second Test Series

The second test series will involve somewhat larger power generation systems and heat pumps. The heat pumps will probably involve open cycles and utilize improved working fluids which yield higher COP's and higher output temperatures. Cost estimates and sizes for the units are given in Table VII-4.

A.4 Facility Expansion

Construction of the EAST Facility in two phases, a core facility and an expanded facility, is recommended because it reduces initial costs and provides needed time to better define the impact EAST will have as well as the ultimate needs of the equipment manufacturer and user communities.

In Plan 1 the requirements for the expanded facility would not be established until the fourth quarter of FY 1984. This time coincides with the completion of installation of the initial system into the core facility and the beginning of systems testing.

It is assumed testing of the second test series can be in progress in the core facility while the expanded facility is under construction, i.e., it is assumed that separate pads are poured for the new area and water supplies are not interrupted significantly. Office space and support areas such as shops can be shared.

It is anticipated the expanded facility will have capacity for testing heat pumps up to 100 million Btu/hr output and power generation systems up to 5 MW. The corresponding flow requirements for the facility would then be 45,000 gpm of heated (150°F) water and 100,000 gpm of cooling (70°F) water. In tests involving smaller systems these flows would provide capability for simultaneous testing of 3 to 4 heat pumps of 10 million-50

TABLE VII-4. EQUIPMENT CAPACITIES AND COSTS*

SECOND TEST SERIES

I. <u>Low Temperature Power Generation System</u>		
Capacity		2 MW
Installed cost for testing at EAST		
@ \$1350/kW		\$2.7 million
II. <u>Heat Pump</u>		
Capacity		25 million Btu/hr saturated steam at 300°F
Installed Cost for testing at EAST		
@ \$50,000/10 ⁶ Btu/hr		\$1.25 million
III. <u>High Temperature Power Generation System</u>		
Capacity		2 MW
Installed cost for testing at EAST		
@ \$600/kW		\$1.2 million
IV. <u>Absorption Chiller</u>		
Capacity		200 tons cooling
Installed cost for testing at EAST		
@ \$600/ton		\$120,000

* 1980 dollars

Btu/hr capacity and a similar number of power generation systems in the 1 to 2 MW range.

The cost of the expansion is estimated to be 50% of the core facility.

A.5 Third Test Series

The third test series will take place in the expanded EAST Facility. It will be possible to begin installation of the systems in EAST in the last quarter of FY 1987. The time required to develop and fabricate the systems prior to installation will depend on the systems to be tested. The test could involve multiples of smaller capacity systems or single large capacity systems. The schedule and cost information in Figure VII-1 and Table VII-1 assume the latter, viz., the tests will involve the proposed Portsmouth systems described in Reference 1:

- One gas turbine-driven, dual-fluid heat pump system with a total output of about 100×10^6 Btu/hr.
- One Rankine cycle power generation system which would use ammonia working fluid and would have a net output capacity of 4.25 MW using water at approximately 150°F.

Figures VII-2 and VII-3 give a detailed breakdown of the schedule for the design, fabrication, installation, and testing of the heat pump and power generation systems. A detailed description of the program, which includes endurance testing of the systems at the EAST Facility but not disassembly, shipment and installation at Portsmouth, follows.

FIGURE VII-2

PROTOTYPE HEAT PUMP SYSTEM DEVELOPMENT SCHEDULE

VS — VENDOR SELECTION

FIGURE VII-3

PROTOTYPE POWER CONVERSION SYSTEM SCHEDULE

*VS --- VENDOR SELECTION

A.5.1. Heat Pump

System Detailed Design

The initial program task consists of three subtasks including (1) detailed system technical and economic analyses, (2) preparation of system layout drawings, and (3) writing specification requirements for all components. The system studies would be conducted to identify the final system design and operating conditions which combines the potential for high performance, high ROI, good operating flexibility, and high reliability. It is also important to identify a design which minimizes development program risks. After the system design is established and component requirements defined, preliminary system layout drawings would be prepared. These drawings would identify component interfaces, piping, electrical and support requirements and overall system dimensions. The drawings and the results of the engineering analyses would be used to prepare detailed specifications for major and auxiliary components and support items. The specifications would incorporate component and working fluid data generated from related programs and data from vendors obtained during preliminary discussions.

The heat pump design incorporates several features yet to be demonstrated in industrial systems. One feature is the use of fluorocarbon working fluids (FreonsTM) at the elevated operating temperatures of 225 to 275°F. Although the use of R11, R113, R114 is being pursued in the development of small heat pump systems for solar and other conservation applications, these systems avoid mixing of the working fluid with oil and employ carefully selected component construction materials. The same requirements will apply to the industrial heat pump systems. One approach to avoid oil contamination of the working fluid is to use an industry-design, open-drive gas compressor equipped with a separate bearing lube system and suitable seals (e.g., isocarbon type). Such compressors are commonly employed in the

petrochemical industry to compress noxious and dangerous chemical gases.

Component Studies

Component investigations would be carried out to select component characteristics (including the choice of working fluid) used in system design. The characteristics of various working fluids (e.g., R11, R113, and R114) would be reviewed to confirm the selection of R11. Working fluid tests would be performed to verify thermal stability and material compatibility at the operating temperatures encountered in the proposed industrial applications. The evaluations would be conducted in conjunction with a supplier of the fluids using a dynamic test loop and existing components (e.g., heat exchangers).

A separate subtask would entail discussions with compressor vendors to identify means of achieving higher compressor performance levels. Life-cycle costing studies have shown that small increases in compressor and system operating efficiency can offset higher capital costs for utility-type applications. Vendors would also be asked to conduct seal tests to demonstrate system working fluid and oil lubrication system compatibility. The seal would be expected to prevent other harmful elements (e.g., moisture) from entering the system.

Component Procurement

Procurement of long-lead components for the heat pump system would be initiated prior to the end of the Detailed Design Studies but after all major component details have been resolved. Past experience and preliminary discussions with vendors indicate that the purchase of large industrial equipment usually takes on the order of one-half to one year from the placement of the order to the time of delivery. An overall procurement time of fifteen months has been allocated in the development schedule (see Fig. VII-2). This will ensure that all critical items are ready for

assembly into the heat pump system installation in a timely and efficient manner.

Assembly and Installation

The smaller and more sophisticated components (e.g., control elements, lubrication system, etc.) would form subassemblies which would be checked out at the developer's facilities and then shipped to the EAST Facility for final assembly and installation. The major and larger components (e.g., heat exchangers and compressors) would be shipped directly from the manufacturer and installed at the EAST Facility. Since this type of equipment is leak checked and/or spin tested by the manufacturer to ensure against mechanical defects, no further individual component testing would be performed until the complete system is assembled.

Foundations for mounting system components would be built at the EAST Facility prior to the arrival of the major components using specifications defined in the Detailed Design task (Figure VII-2) and updated by information supplied by the component vendors. As the components are set in place interconnecting piping, instrumentation and electrical hookups would be made.

System Testing

After the heat pump system is completely assembled, checking and green running of the system would be performed. Finally, performance and endurance testing would be conducted. Initially, the refrigerant and water piping circuits would be leak tested at room temperature. Similarly, instrumentation sensors and data collection equipment would be calibrated and adjusted as required. After the system is leak free and the instrumentation approved, the entire system would be fired up and operated over a limited range of gradually increasing temperatures and power levels. During this break-in period leak checks and instrumentation verification would be continued. Critical items

such as compressor and engine vibration levels would be monitored. The green testing is used to verify mechanical features of the system.

After green testing the system would be performance tested over a wide range of operating levels. Sufficient data would be collected to identify the overall performance of the system and to define the performance of each major component. Temperature, pressure and flow rate measurements in and out of each heat exchanger would be used to define overall heat transfer coefficients and its pressure loss characteristics. Similar information would be used to define the performance characteristics (e.g., adiabatic efficiency) of the compressors and the gas turbine driver. The results of these tests would also define the pressure drop characteristics of the system interconnecting piping and identify possible changes or adjustments to the control system.

Continued performance testing over an extended period (~4000 hrs) would constitute the endurance program. Certain critical items would be monitored to detect deterioration of component performance. For example, reductions in heat transfer coefficients and increases in pressure losses would be indicative of heat exchanger fouling. Similarly, bearing mechanical problems would be detected by monitoring vibration measurements. Also samples of the working fluid would be taken periodically and analyzed for possible contamination by the compressor lubricating oil and for the presence of decomposition products.

The results of the endurance testing would be used as a basis for the developer making minor modifications to ensure that the heat pump will operate at high performance in a reliable and trouble-free manner when installed at the Portsmouth CEMS. These results would also provide the basis for preparing normal overhaul and maintenance schedules.

Test Plan

Early in the program, a preliminary test plan would be formulated to satisfy DOE's test objectives. The plan would describe the various EAST Facility resources to be used, including equipment, materials, utilities, personnel, and services, and a proposed schedule for their use. The plan would define the types and locations of instrumentation and control devices to be used and the data acquisition/processing scheme to be followed. The formulation of a final test plan would follow negotiations between the DOE test requestor and the facility test engineer regarding cost and schedule considerations. Subsequently, detailed test operating procedures would be defined.

Costs

The total estimated cost of the development program to design, fabricate, and install the 100×10^6 Btu/hr heat pump system in the EAST Facility would be from \$5 to \$8 million. The costs of conducting the 9-month test program would include all the direct costs of equipment, supplies, fuels, utilities, personnel, services, and logistical support, plus a portion of indirect costs attributed to general facility operation during this period. Special modifications and demodifications of the facility would add to these costs. Proposed testing costs would be negotiated with the test plan, as mentioned above.

A.5.2. Power Generation System

System Detailed Design

The initial program task consists of four subtasks including (1) verification of critical component design parameters, (2) engineering analysis, (3) preparation of system layout drawings and (4) preparation of component specifications.

Two critical component parameters which need verification are the fouling coefficient to be used in the design of heat exchangers and the seal selection to be used in the ammonia turbines. The fouling coefficient represents the dominant thermal resistance in the heat exchangers and must be firmly established before proceeding with design. To determine it, the experience at Federal facilities, particularly Portsmouth, would be reviewed including experience with automatic cleaning systems. If necessary, a laboratory-scale circulating water loop simulating a cooling tower system would be tested over a period of several months to verify the specification of the fouling coefficient. The turbine seal is the mechanical component most likely to fail, and its failure would result in a contamination problem. To select the seal type, experience with existing high speed ammonia seals would be reviewed. If necessary, seal rig tests would be conducted to verify seal performance and endurance at the pressures and rotating speeds expected at the turbine.

Having established the fouling coefficient and seal type, the components could be designed and constructed by qualified vendors since they are similar to others already developed. The components and piping may be fabricated from aluminum and ferrous alloys without corrosion problems as demonstrated by experience in the OTEC program and in ammonia refrigeration systems. Power recovery expanders of the type proposed have operated

successfully on gases containing ammonia* and a small unit of this type was operated successfully on pure ammonia in a demonstration system. The boiler, a vertical natural circulation design, would be similar on the boiling side to a process condenser-reboiler. The condenser and feed heater are smooth tube designs and would be sized on the basis of well known heat transfer correlations. Available feed pump and circulating pump designs may be adapted to the ammonia system requirements.

As indicated in Fig. VII-3, an eight-month period is required for system design. This includes engineering analysis to establish thermodynamic conditions, flows and component sizes, layout design to establish the system configuration and piping requirements, and the preparation of component specifications.

Component Procurement

Procurement of the power system components would be initiated after all major component details have been resolved. A competitive vendor selection procedure would be carried out for each major component. This is estimated to require a month's duration. The selected vendor would make a detailed design of the component and submit drawings for approval. On the basis of preliminary information from qualified vendors, the longest design time, approximately three months, would be required for the boilers. Procurement of materials and fabrication of components would take place after design approval. The longest fabrication time, approximately twelve months, would be required for the boiler. The boiler and the other heat exchangers would be pressure-proof tested and helium-leak tested before delivery. The turbogenerators would be run up to speed at the vendor's plant using an air or steam supply instead of ammonia. All components would be ready for shipment approximately 24 months after program initiation.

*Private advice from the Rotoflow Corporation, 1979.

System Installation

System installation includes (1) the construction of foundations and supports, (2) mounting the major components and (3) attaching ammonia and water piping, and hooking up all electrical wiring (including instrumentation). The construction of component mounting structures would be started approximately in the 20th month so that the components could be installed at the EAST Facility when available. Component installation would be followed by pipe installation, electrical hookup and instrumentation installation. The system would be checked for leak tightness using helium. All instrumentation would be checked by measuring circuit resistances and reading ambient conditions.

System Testing

The test program would be comprised of transient testing and combined endurance and seasonal performance testing. The transient testing, estimated to be of one-month duration, would include startup, shutdown and load dropping tests to demonstrate control stability and system response rate. Seasonal performance tests over a six-month period would measure system power conversion efficiency for most of the hot water and cooling water conditions expected at Portsmouth during a year. Operation during this elapsed time plus the inclusion of a prescribed number of starts and stops would establish the endurance of the power plant. The completion of the program is estimated to occur at the end of the 39th month. The overall period of test conduct will include developer testing of equipment performance monitored by the EAST team, followed by independent testing of equipment performance/reliability/maintainability by EAST personnel assisted by a developer's team as necessary.

Cost

The total cost of the power system development program shown in Fig. VII-3 including the tasks of designing the system, procuring the components, and installing the components in EAST is estimated to be from \$6 to \$10 million.

B. Plan 2

The overall schedule and costs for Plan 2 are given in Figures VII-4 and Table VII-5. This plan compresses the schedule to the maximum degree which we think possible to achieve maximum volume testing capability at the earliest date.

The first test series, identical to Plan 1, begins in the last quarter of calendar year 1983 approximately 9 months earlier than in Plan 1. The primary reason for this earlier milestone is compaction of the rather conservative construction schedule in Plan 1. Plan 2 increases the testing period of the first test series by an additional 60% to allow for possible reactor outages and additional contingencies during initial testing.

In Plan 2 construction of the expanded facility is completed about 9 months earlier than in Plan 1. The second test series for the core facility in Plan 1 is dropped and thus the third test series in Plan 1 becomes the second test series in Plan 2.

The primary advantage of the accelerated schedule is that the facility attains greater throughput earlier and accordingly saves more energy by shortening the time to achieve maximum market penetration. The primary disadvantages are that the learning curve in progressing from the core facility to the expanded facility is abbreviated and programmatic funding in the earlier years is increased.

FIGURE VII-4 EAST FACILITY SCHEDULE - PLAN 2

TABLE VII-5
EAST FACILITY COSTS - PLAN 2
(THOUSANDS OF 1980 DOLLARS)

<u>TASK</u>	<u>FY 81</u>	<u>FY 82</u>	<u>FY 83</u>	<u>FY 84</u>	<u>FY 85</u>	<u>FY 86</u>	<u>FY 87</u>
CORE FACILITY							
DESIGN & CONSTRUCTION	1000	4300	4300				
PRE-TEST OPERATIONS			150				
FIRST TEST SERIES							
FABRICATION & INSTALLATION		200	1490	400			
TESTING				1900	3600		
FACILITY EXPANSION							
DESIGN & CONSTRUCTION			300	2000	2500	200	
SECOND TEST SERIES							
FABRICATION & INSTALLATION				5000	6000	5000	
TESTING						3900	3900
TEST EVALUATION, PLANNING & ANALYSIS	<u>400</u>	<u>400</u>	<u>400</u>	<u>400</u>	<u>400</u>	<u>400</u>	<u>400</u>
TOTAL	1400	4900	6640	9700	12500	9500	4300

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APPENDIX A

SCOPE OF WORK FOR REQUIREMENTS DOCUMENTATION

Subtask 1 - Waste Heat Resource/Applications Analysis

The work in this subtask will provide an extensive description of the potential market sources for waste heat recovery systems. This description will be broad in nature and will be used to form the boundaries (i.e., fluid state temperature and flow) for system applications.

A second area will provide a more detailed assessment of heat recovery opportunities in South Carolina. This study may well be the basis for some of the early applications for the heat recovery systems.

Subtask 2 - Test Article Descriptions

In this subtask, concepts for actual heat recovery systems will be developed. These concepts should fit within the boundaries of the sources described in Subtask 1. All the specifications needed to describe the test article, test operations, and interfaces will be delineated.

Subtask 3 - Test Programs and Operations

In this subtask, the general objective and overall scope of the testing program and operations will be described. Using the requirements developed in Subtask 2, a developmental and system reliability test program will be developed including timing, manpower, and safety related considerations.

Subtask 4 - Facility Support Systems

The work in this subtask will provide a description of all the support systems required to install the test articles described in Subtask 2 and to carry out the test programs described in Subtask 3.

Subtask 5 - Physical Plant

In this subtask, the work will be culminated in a description of the facility itself. Since the function of the facility will be to provide a source for developing and demonstrating new heat recovery equipment, it must have a high standard of reliability and quality assurance. These standards will be described in this subtask and will result in facility qualification requirements prior to the initial test program.

The facility will be described in terms of its functional requirements (i.e., performance characteristics, useful life, schematics, and human performance) and its ability to meet long term growth. Special environmental, safety and health considerations will be identified.

In accomplishing the above scope of work, ERI will act as the focal point for all activity and will be responsible for integrating all information into the final requirements document. There will be two main deliverables: A basic requirements report delivered on January 15, 1981, and amendments to that report on March 16, 1981 containing comments from other manufacturers. During the period leading up to the January 15 report, and thereafter, developing requirements will be issued using a formal release and change control procedure.

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