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GRID-CONNECTED INTEGRATED COMMUNITY
ENERGY SYSTEM

Final Report, Volume 1, Phase II, August 9, 1977–
March 22, 1978

Work Performed Under Contract No. EC-77-C-02-4211

Clark University
Worcester, Massachusetts

U. S. DEPARTMENT OF ENERGY

Division of Buildings and Community Systems

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GRID-CONNECTED INTEGRATED
COMMUNITY ENERGY SYSTEM

FINAL REPORT, VOLUME I

PHASE II

FOR PERIOD

AUGUST 9, 1977 TO MARCH 22, 1978

CLARK UNIVERSITY
950 MAIN STREET
WORCESTER, MASSACHUSETTS 01610

PREPARED FOR
THE U.S. DEPARTMENT OF ENERGY
UNDER CONTRACT NO. EC-77-C-02-4211.A001

PREPARED BY
CLARK UNIVERSITY
THERMO ELECTRON CORP.
FITZMEYER AND TOCCI, INC.
BOZENHARD COMPANY
SHEPHERD ENGINEERING
NEW ENGLAND ELECTRIC SYSTEM
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1. INTRODUCTION

Clark University represents an attractive site for demonstration of cogeneration. The principal features of the site are as follows.

(1) Clark is located in New England, a region that depends on imported oil for most of its electric generation, and has some of the highest electric prices in the nation.

(2) Clark, with a 1.5 MW peak electrical demand, offers a variety of demand patterns in its 20+ major buildings.

(3) Clark already has an operating steam distribution system which serves its 12-acre campus.

(4) Clark is serviced by the Massachusetts Electric Company, an organization that has taken an active and creative interest in cogeneration.

In Phase I of the ERDA Demonstration ICES Program, the team from Clark University, consisting of representatives from the University, Thermo-Electron Corporation, Fitzmeyer and Tocci, and Massachusetts Electric, reported the following results:

(1) The system of choice for ICES demonstration at Clark is a diesel generator sized at about Clark's peak electric demand.

(2) In order to avoid placing additional demand on scarce light-oil sources, such a generator should burn #6 oil if at all possible.

(3) Through Massachusetts Electric's agreement to purchase excess power at about the cost of displaced fuel, the system can run at nearly full capacity the year round, sell 40% of its output to the utility, and receive backup as needed from the utility.

(4) Under a variety of possible financing plans and reasonable projections of fuel costs the system will deliver for Clark an internal rate of return of 15-20%.

(5) There appear to be no institutional or environmental problems that would prevent operation of the system as planned.

In this report we provide an update on a number of issues that were incompletely resolved in the Phase I report.

In Section 2, we provide additional documentation on institutional

issues involved in the proposed demonstration at Clark, particularly as follows.

(1) We are assured through inquiries at the State Attorney General's Office that Clark, a non-profit institution, will be able to sell power to the utility without affecting its tax-exempt status. The principal reason for this finding is that the sale of power is considered "incidental" to the production of heat.

(2) We now have an agreement with Massachusetts Electric that both we and the utility can support. The agreement provides for power on a standby basis to Clark when the ICES is not generating; it also describes terms for sale of power by Clark to the utility.

(3) We are assured that we can obtain adequate financing through a 6-7% interest HEFA tax-exempt bond issue. This makes the proposed ICES financially viable for the University. In addition we are eligible for federal loan programs at 3% interest rate, and are currently exploring these with help of Worcester's Congressman Early.

(4) We have had new worries about air pollution because of the introduction of short-term standards for nitrogen oxide concentrations; however, it now appears that the plant will not violate either new or existing federal and state regulations.

(5) There are no other serious environmental problems.

(6) There are, in addition, no problems with building codes, zoning and fire ordinances.

In Section 3 we provide a preliminary design analysis that clearly defines our choice of engine and provides revised operating data in light of additional load profile studies. In particular we now find:

(1) A Sulzer #6 oil burning 1405 KW diesel with ebullient cooling and exhaust gas heat recovery is the system of choice.

(2) The engine and heat recovery system should be housed in a separate building in close proximity to the existing boiler and steam distribution center.

(3) As a result of summer load studies we have determined that the engine as specified can be operated with a capacity factor of 90%, instead of the Phase I estimate of 85%.

In Section 4 we present a summary of our preliminary design package. This includes sufficient detail to make a much more reliable estimate of capital and construction costs. Major items included here, but not previously, are a fuel treatment facility, preliminary design of a building, preliminary layouts of equipment, including a cooling tower on the roof of an existing building.

In Section 5 we provide a financial analysis based on our design package. In comparison to Phase I, capital costs have increased considerably due to the addition of a separate building, fuel treatment, and the use of a more expensive #6-oil-burning engine. These costs are in part cancelled by lower cost of #6 oil, and by the more favorable summer heat load picture that has emerged since Phase I. As a result we find that the project continues to be financially viable. Specifically, we project a 9.4 year payback period, on a total Clark investment of \$1.5 million. Total cost, including DOE-financed feasibility studies and demonstration aspects, is projected at \$2.2 million. Replication cost for a facility like Clark's, but without feasibility and demonstration aspects, is projected at close to Clark's cost of \$1.5 million.

Thus we find, as before, that the Clark ICES system is a generally attractive project. From a national point of view it clearly demonstrates grid connected cogeneration through the sale of 40% of Clark's output and a net fuel saving of 30%. From Clark's point of view it serves as a sound investment and a useful hedge against inflation and future changes in utility rate structure.

The resolution of the Clark Trustees on project continuation, as voted at a meeting of the Executive Committee on March 15, 1978, reads as follows.

The Trustees have examined the results of the ICES study and are encouraged by its findings. In order to continue progress and to protect the interest of DOE and the University in this project, the Trustees take the following actions:

VOTE #1: To authorize the Treasurer 1) to seek preliminary approval from HEFA to borrow up to \$1,750,000 (includes reserve requirements and expenses of \$250,000) in order to construct ICES servicing the Clark Campus, 2) to make appropriate applications to the federal government for subsidized loans or grants, and 3) to negotiate with DOE for selection of the University as a demonstration site for an ICES.

VOTE #2: To authorize from unrestricted capital gift income \$15,000 to be used as up-front planning money during the early stages of Phase III, until all pending issues are fully resolved. Expenditures shall be approved by the President upon the recommendation of a special subcommittee which will include the co-chairmen of the Board of Trustees, Chairman of the Finance Committee, the University's Counsel, the Treasurer, and the Dean of Academic Affairs.

To prepare for a final decision to go ahead with the project (expected late August, 1978), the University will apply this-summer for financing under two federal energy conservation loan programs. Clark will also seek the necessary permits from the Massachusetts Department of Environmental Quality Engineering, and will begin those aspects of final design necessary to ensure that construction can begin June, 1979.

2. INSTITUTIONAL DOCUMENTATION

2.0 Introduction

In Phase I we identified several institutional issues which had to be resolved. These critical issues were (1) whether the University has the power to sell electricity, (2) whether we could make suitable arrangements for interchange with Massachusetts Electric that would be approved by the Massachusetts Department of Public Utilities (DPU), (3) whether we could find a suitable mode of financing the system, and (4) whether the plant would meet environmental and zoning requirements. These issues are resolved (or nearly resolved).

2.1 Corporate Power

We had initially hoped to obtain a formal ruling from the Attorney General on whether the University as a charitable institution has the power to sell electricity. However, since we are not a government agency, we are not entitled to a formal ruling. We have instead been given an informal opinion by the division in the Attorney General's office responsible for overseeing charitable institutions. In the opinion of Assistant Attorney General Reedy (letter in Appendix 2A), "the distribution of excess energy to a public utility would be incidental to the primary purposes [of the project], and would not affect the charitable status of the University." According to the University Counsel, Richard Mirick, since this is from the division of the state government charged with supervising the conduct of charitable institutions, it is sufficient assurance that the University's power to sell electricity will not be challenged (see Mirick's letter in Appendix 2A).

2.2 Interchange Terms

Clark and the Massachusetts Electric Company have agreed on terms for interchange along the lines described in our Phase I report. Letters from William Cadigan, President of Massachusetts Electric, and Richard Mirick, University Counsel, appear in Appendix 2A. The agreement is given in Appendix 2B. We plan to submit the proposed contract to the DPU this summer. As the contract is acceptable to both Clark and Massachusetts Electric, we expect DPU approval within 30 days of our submission.

Key features of the contract are as follows. The contract will be in effect for 20 years, the nominal life of the plant; Clark will have the option of switching to a future cogeneration rate if the terms seem prefer-

able. The agreement empowers Clark to use directly as much of the ICES electricity output as Clark needs. Only when the ICES output is insufficient for the Clark demand will Clark purchase electricity from Massachusetts Electric. Clark has two options for purchases, but must choose one for the duration of the contract. One option is simply to use whatever auxiliary service rate is in effect at the time. At present Clark would guarantee a minimum monthly payment based on its contracted demand and would make all purchases under one of the regular retail rates. Because Massachusetts Electric has informed us that they expect this auxiliary rate to change in the near future and because Clark wished for terms which would be defined over the twenty year life of the contract, Massachusetts Electric has offered Clark a second option. This option would require that Clark pay a monthly charge for distribution capacity based on contracted demand, and pay for all purchases under a retail energy rate, G-22, or the equivalent. The monthly charge would go from \$1.00/kw to \$2.00/kw in five years, then remain fixed at \$2.00/kw.

When Clark makes more electricity than it can use, the excess will be sold to the utility for a price closely approximating the cost of displaced fuel. This price depends on time of day; thus there will be two prices, one for weekdays from 7:00 A.M. to 11:00 P.M., the other for the remaining times. For convenience, the price will be factored into two pieces, a multiplier times the average wholesale fuel cost. There will be two multipliers, one for peak and the other for off-peak sales. For 1978 Massachusetts Electric has estimated the peak multiplier to be 1.45, and the off-peak multiplier to be 1.25. The multipliers will be reevaluated yearly to take account of changes in the mix of generating costs.

2.3 Financing

In Phase I we identified four alternative modes of financing the ICES. These were borrowing from the endowment, a commercial loan, a Health and Education Facilities Authority (HEFA) tax-exempt bond issue, and federal loan programs. We found that the last two possibilities were distinctly preferable, but we were not able to definitely determine their feasibility. At present we can report that we would have been eligible under last year's HUD loan program had we been ready to begin construction soon enough. The HUD program provides loans for investments for the purpose of conserving energy in dormitories and dining facilities. Since about half of Clark's heat and electricity go to dormitories and dining (see Phase I Report,

Tables 1.2.4-2 and 1.2.4-3), this program could provide financing at 3% for half the project cost. The program has been funded again this year and final regulations should be published very soon. Another program covering all university buildings is administered by the Office of Education; it was not funded last year, but funds have been released for it this year. This program will also make some matching grants. We are prepared to submit applications for either program the moment final regulations are published, early this summer.

Because federal financing is not certain, we have spent considerable effort in seeking approval for a HEFA bond issue. We have retained an investment broker, Marsom Pratt of Adams, Harkness and Hill, to handle the bond issue. Mr. Pratt is investment counsel to HEFA. In 1976 he developed the successful bond issue for Clark's new Student Activities Center and he is confident that a HEFA bond issue can be developed for the ICES and that it will be approved by HEFA. He recommends that we place the bonds privately, instead of having a public issue. For a private issue, Clark will not need to tie up resources in securing the bonds, and approval and placement will be easier to obtain. We will, however, have to pay a higher interest rate than the 5% we paid on the public issue for the Student Activities Center. The interest charges will not exceed 7% in any event. HEFA approval for the bond issue must come in two stages. We have obtained preliminary approval for the bond issue. Preliminary approval authorizes the preparation of a prospectus for the bond issue. We expect to obtain final approval for the bond issue after a review of the proposed prospectus. The prospectus can, however, be completed only with the preliminary design results of Phase II; consequently, final approval of the bond issue can only be obtained after the completion of Phase II. At the same time Pratt assures us that, with the cost analysis presented in section 5 of this report, there will be no difficulty in obtaining final approval. (See letter from Marsom Pratt in Appendix 2A.)

Pratt has also suggested the use of the leveraged lease as another mode of financing. This may offer even better terms than the HEFA bond issue. Under this plan an investor would own the facility and lease it to Clark. He would be able to offer good terms because he could take advantage of tax benefits, investment tax credit, accelerated depreciation, etc., which do not apply to the University. This mode of financing was used for the Harvard Hospitals' total energy plant.

To summarize, we feel confident that we can obtain financing through a HEFA bond issue, and are taking the necessary steps to achieve this. We are continuing to pursue two alternative possibilities which might offer even better terms, namely federal loan programs and a leveraged lease. While we do not regard borrowing from the endowment as a satisfactory method of long-term financing, it is technically possible for us to borrow for this purpose, and this provides us with enough flexibility to meet unforeseen short-falls.

2.4 Air pollution impact

The net effect of the proposed Clark ICES is to increase air pollutant emission in the immediate neighborhood of the University, and to decrease emission at more distant utility power plants. Details are discussed in Appendix 2C. A summary of effects may be read from Tables 2.4-1 and 2.4-2 indicating annual and peak emission rates.

With respect to published federal standards Worcester is currently a non-attainment area in three pollutants: particulates, CO, and oxidants. Worcester is an attainment area for two other pollutants: SO₂ and NO₂. (There are no standards for HC.) For a non-attainment area the Clean Air Act Amendments of 1977 require a permit from local authorities for new sources emitting over 100 tons per year of the non-attainment pollutant. Sources under 100 tons are unregulated. For an attainment area, federal legislation requires that new sources emitting over 250 tons of a given pollutant not affect ambient levels beyond a certain "significant increment of deterioration." Sources under 250 tons are unregulated.

A glance at Table 2.4-1 shows that under the present definition, all non-attainment pollutants emitted by the ICES are under 100 tons annually, and all attainment pollutants are under 250 tons annually. It is for this reason that we concluded in earlier reports that there is no problem in meeting air pollution standards.

Very recently, however, it has become clear that the EPA is moving toward setting hourly maximum standards for NO₂. It is possible that these could make Worcester non-attainment in NO₂. At that point our emission of 179 tons of NO₂ per year would require us to show that ambient levels produced by the local plant do not materially aggravate NO₂ levels, especially at "sensitive targets" in the local neighborhood. Demonstration of this would require use

Table 2.4-1: Annual Air Pollution

System	Annual emission in tons				
	SO ₂	NO ₂	CO	HC	Particulates
<u>Present system</u>					
Utility boiler	36	25	-	0.5	1.5
Clark boiler	78	54*		1.0	3.2
System impact	<u>114</u>	<u>79</u>		<u>1.5</u>	<u>4.7</u>
<u>ICES System</u>					
Clark diesel	57	155	24	11.2	0.5
Clark boiler	56	39*	-	0.7	2.3
Utility boiler	-22	-15	-	-0.3	-0.9
System impact	<u>91</u>	<u>179</u>	<u>24</u>	<u>11.6</u>	<u>1.9</u>

*may be overestimate

Table 2.4-2: Peak Air Pollution Rates

System	Peak emission rate in grams/second				
	SO ₂	NO ₂	CO	HC	Particulates
<u>Present system</u>					
Clark boiler	<u>4.0</u>	<u>3.7*</u>	-	-	<u>0.02</u>
<u>ICES System</u>					
Clark boiler	3.5	3.2*	-	-	0.02
Clark diesel	1.8	5.0	0.8	0.4	-
Total	<u>5.3</u>	<u>8.2</u>	<u>0.8</u>	<u>0.4</u>	<u>0.02</u>

*may be overestimate

of certain EPA designated computer models, and interpretation of results obtained from these in light of existing hourly maxima.

In anticipation of the forthcoming EPA hourly maximum standards we have been working with Ed Benoit, Chief of the Central Massachusetts Air Quality District. Benoit has in fact obtained preliminary computer results using the peak emission rates indicated in Table 2.4-2. From these he observed that our boiler plant has nearly as large an impact as the proposed ICES. We have subsequently measured NO emissions from our boilers and obtained values less than 1/4 those in Tables 2.4-1 and 2.4-2; however, these measurements were made while the boiler was burning gas and do not include NO_x production from bound nitrogen in residual oil. Maximum hourly effects of the combined Clark system on six sensitive targets in the near neighborhood ranged from 50 to 300 $\mu\text{g}/\text{m}^3$. The peak concentration from the diesel plume is nearly 200 $\mu\text{g}/\text{m}^3$. If the forthcoming EPA standard is set at 200 $\mu\text{g}/\text{m}^3$ the project appears to be in trouble. According to Benoit, who has considerable modelling experience, 200 $\mu\text{g}/\text{m}^3$ would place in jeopardy nearly every new NO₂ source of 100+ tons in urban Massachusetts. Benoit has, however, assured us that we have no difficulty with other air quality regulations (see letter dated April 5, 1978, in Appendix 2D).

Further complicating the picture is the fact that recently, under intense community pressure, the Massachusetts Department of Environmental Quality Engineering (DEQE) has issued an order halting construction of a 22 MWe, six-diesel, total energy plant being built by Harvard University in downtown Boston. The impact of this project, which has total NO₂ emissions about 16 times our annual amounts, was estimated at 230 $\mu\text{g}/\text{m}^3$ hourly maximum for certain "sensitive" targets such as homes for the aged, and hospitals. Added to ambient hourly maxima of 300 to 400 $\mu\text{g}/\text{m}^3$, the Harvard project was believed to be capable of producing hourly maxima in the range of 500-600 $\mu\text{g}/\text{m}^3$ at certain downtown Boston locations. The principal finding of DEQE Regional Environmental Quality Engineer McLoughlin in the Harvard University case is that existing federal NO₂ regulations are too lax, and allow the possibility of serious health effects. A proper interim safety level, according to McLoughlin, is 200 $\mu\text{g}/\text{m}^3$ hourly maximum. It is for this reason that Harvard's project was disallowed.

At present the Massachusetts DEQE interim standard 200 $\mu\text{g}/\text{m}^3$ will not apply to sources of less than 250 tons annually (see E. Benoit letter dated May 2, 1978, Appendix 2D) and hence the Clark project will not be affected by

the interim standard. If Worcester is not in compliance with the forthcoming EPA standard (which will supercede the interim Massachusetts Standard), the Clark project will require review. Benoit believes (April 5, 1978 letter, Appendix 2D) that there will be no difficulty if the EPA standard falls in the range 470 - 940 $\mu\text{gm}/\text{m}^3$, now under consideration (March 27, 1978, Federal Register).

A further change in air pollution regulations is the forthcoming EPA emission standards for diesel engines. These are the responsibility of the diesel manufacturer and so will not affect Clark except insofar as they limit the availability or performance of engines. The EPA draft proposed standard calls for a limit on NO_x emissions of 6 gms/bhp-hr, to go into effect 15 months after promulgation (Draft Summary of the Recommended Standard of Performance for Stationary Reciprocating Internal Combustion Engines, EPA, March 23, 1978). This can be compared with the emission of 8-9 gms/bhp-hr of the Superior and Sulzer engines and up to 18 gms/bhp-hr of certain diesels. The proposal has generated considerable controversy as very few present-day diesels can meet it without major impairment of performance that, together with the 15-month waiting period, makes it extremely unlikely that emissions standards will cause Clark any difficulty. Sulzer has stated that they could reduce emissions to 7 or 7.5 gms/bhp-hr with only a modest deterioration in engine performance.

To summarize then, the most sensitive air pollution produced by the proposed ICES is NO_x . We have good indications that the ICES will comply with all applicable present and future air quality regulations, but we are continuing to watch closely as EPA develops standards for short term NO_x concentrations and standards for diesel emissions.

2.5 Other Environmental Issues

Other potentially deleterious environmental impacts of the ICES are water pollution from the fuel treatment, increased traffic due to increased oil deliveries, noise from the plant, traffic, noise, and air pollution during construction, and changes in the aesthetic character of the campus. It is our judgement that all of these problems are small or negligible.

Water pollution. Oil treatment effluent will not exceed 18 gallons/hour. This effluent will contain less than 80 ppm oil, 600 ppm sodium chloride, 70 ppm lead, 50 ppm calcium chloride, 5 ppm potassium, and 50-100 ppm magnesium. This is too small an effluent to affect the operation of the Blackstone Pollution Abatement District or water quality generally. (See letter from Michael Burke, Appendix 2D.)

Noise. Noise from the plant will not change ambient levels as described in section 4.5 and Appendix 4G.

Increased oil deliveries. The number of oil deliveries will be increased about 50% from the present 120/year. This will be noticeable on the Clark campus, but not in the adjacent heavily commercial Main Street area.

Construction. We expect most construction to be concluded while the campus is largely unoccupied during the summer, so that adverse effects will be comparatively minor.

Aesthetics. As discussed in section 4.3, there has been considerable University concern about the aesthetic impact of adding a large structure to the center of the Clark campus. This concern has recently been resolved by the discovery that we can reduce the building volume by at least 40%; the Clark Trustees now believe that the building can be made to fit in well with the surrounding campus.

2.6 Building Code, Zoning, and Fire

We have been assured that the proposed ICES design can meet all building code, zoning, and fire regulations. Final permits can be issued only after submission of final working drawings. (See Appendix 2D.)

2.7 Labor Relations

Clark physical plant staff will operate the ICES. The staff have been closely involved in the planning for the ICES and we anticipate no labor-related difficulties in plant operation.

For the construction of the plant, Bozenhard said that he foresees no problems with local unions. The job has been budgeted for union labor and would be bid by union-affiliated contractors. Present construction labor relations are good.

3. PRELIMINARY DESIGN ANALYSIS

3.0 Introduction

Our preliminary design analysis incorporates a number of changes from Phase I. We have found that our summer thermal demand is not quite what we had estimated, and the correction will enable the ICES to generate somewhat more heat and electricity. We have decided to locate the generating system in a new building outside Jonas Clark hall. Most important, we have found a diesel system which meets essentially all of the requirements we defined in the Phase I analysis. It is a Sulzer engine, Model 8 ASL 25/30; it is ebulliently cooled, burns #6 oil, and produces about 1400 KW of electricity. With the #6-burning engine, we need one more subsystem for the conceptual design, a fuel treatment system.

In the next section, 3.1, we present our new results on thermal demand, and describe the electrical and thermal outputs of the new diesel. In section 3.2 we review the Phase I choice of system and then give our reasons for selecting the Sulzer engine and the new location. In section 3.3 we describe the changes needed in the conceptual design to accomodate the new engine and location.

3.1 Energy Load Profiles

The electricity load profile presented in our Phase I report was based on several years of recorded data. Since our recent data is consistent with the previous records, we have not altered our estimated electricity load profile. The profile contains an estimated contribution from the new gym; the estimate is consistent with preliminary data from the first month the gym has been in use.

The thermal load profile presented in the Phase I report used estimated summer thermal demands. We now have data on thermal demand for this summer and this changes somewhat our previous estimate. We have found that at present summer thermal demand is considerably more uniform than we had estimated. As with the electrical profile, we have estimated the contribution of the new gym and our estimate is consistent with preliminary data. The added demand in summer nights means that we will be able to operate the ICES, at part load, for many summer nights, and the overall output of the system will be somewhat greater than our previous estimate.

We repeat the electric load profile and present our new thermal load profile in Fig. 3.1-1. Shown on these profiles are the electric and thermal outputs of the Sulzer 1405 kw engine. Except for summer nights and brief periods for maintenance, the engine operates at full load continuously. The overall fuel saving we expect is about 300,000 gals/yr oil saved by Clark and the electric utility. Notice that the grid-connection, in addition to its other benefits, gives rise to about 40% of those savings.

We show fuel consumption and savings on an annual basis in Figs. 3.1-2, 3.1-3, and 3.1-4. Fig. 3.1-2 compares Clark's annual heat and electricity demands with the ICES output. Fig. 3.1-3 shows the total annual fuel savings produced by the ICES (approximately 8000 barrels/year). Fig. 3.1-4 shows the increase in fuel use at Clark (approximately 10,000 barrels/yr) illustrating why there is a local increase in air pollution, but a system-wide reduction in particulate and SO₂ emissions.

3.2 Design Options and Final Choice of Engine

We have decided to put the generating plant in a new building adjacent to the boiler room in the basement of Jonas Clark hall. This location is preferable to a location inside Jonas Clark, because (1) it avoids major problems with noise and vibration insulation; (2) it does not eliminate classroom space; (3) it will be much easier to make the demonstration system accessible and attractive for public viewing. The disadvantage of the choice is that it adds significantly to the capital cost of the project (see section 5.1 and Appendix 5A). We believe that the advantages more than make up for the extra cost.

In Phase I we concluded that the optimum ICES for Clark would use a single diesel engine, ebulliently cooled, burning residual oil, with a maximum electricity output of about 1500 KW and a maximum recoverable heat output of about 4 million Btu/hr. We reached this conclusion after examining a variety of diesel engines in various configurations along with representative steam turbine systems and gas turbine systems. We have reviewed that analysis for this report and found it still correct. Steam turbines small enough for Clark's heat demand simply do not make enough electricity to finance them. Gas turbines suited to our size burn distillate oil and have slightly poorer performance characteristics than comparable light-oil-burning diesels. Ebullient cooling is necessary because the University has

Fig. 3.1-1: Electric and Thermal Outputs of Sulzer Engine

Fig. 3.1-2. Yearly Energy Balance

Fig. 3.1-3. Fuel Savings with Respect to the Displaced System

Fig. 3.1-4: Fuel Use at Clark

a steam heating system and it would be prohibitively expensive to make the modifications needed for heating some buildings with hot water. There are two advantages to burning residual oil; it is significantly cheaper, and it is in the national and regional interest not to add to the pressure on the demand for light oil and gas. Grid-connection obviates the need for multiple engines, as we don't have to follow Clark's electrical demand and as we are not considering engines large enough to require extensive variation of heat output. Finally, the size of the generating system is fixed by economic considerations. While it is profitable to sell excess electricity to the utility, it is not sufficiently profitable under the present terms to finance capacity which is solely for exports. Thus the optimum generator will produce approximately as much electricity as will meet Clark's peak electrical demand.

In Phase I we made our analysis using a diesel generating system which met all of the above requirements except for one; the engine burned only distillate oil, not residual oil. Since then we have identified two candidate diesels of the right size which can burn residual oil and be cooled ebulliently. These are a 1400 KW engine made by Sulzer, model 8 ASL 25/30, and a 1500 KW engine made by Cooper Bessimer, Superior model 40-X-16. The Sulzer engine is normally water cooled, not ebulliently cooled; however, the Sulzer Company assures us that the alterations are minor ones and that they are happy to maintain their standard one-year guarantee. The Superior engine normally burns distillate oil; the manufacturer, Cooper Energy Systems, is willing to modify the engine to burn residual oil. They too will maintain their one-year guarantee, with the proviso that the fuel entering the engine be carefully monitored to ensure strict limits on sodium and vanadium in the fuel.

Since both manufacturers are confident that the modifications will not impair the performance of the engines and since they will guarantee the engines, we feel that both engines are viable options. Since they offer a significant economic advantage over the distillate-fired engine, we would prefer one of them as the generator for the grid-connected ICES. It is worth noting that, according to Thermo-Electron, both manufacturers have thoroughly competent field service representatives. Sulzer's U.S. service is performed by Colten Marine, Brooklyn, New York, who have worked many years on residual-burning marine diesels. Superior has its own field service team which also has much experience.

We chose the Sulzer engine in preference to the Superior for the following reasons. (1) We believe that the burning of residual oil is a more sensitive modification than the change to ebullient cooling. Sulzer has both laboratory and field experience with burning #6 oil in that engine. That experience is summarized in Appendix 3A. (2) Sulzer places slightly less stringent limits on vanadium and sodium than Superior. (3) The Sulzer engine gives a slightly better return on investment (see section 5.3). (4) The Sulzer engine is smaller and will be easier to install.

Each of these is a small consideration, but taken together they lead to a preference for the Sulzer engine. This preference could be reversed by a continuing decline of the dollar relative to the Swiss franc, which would make the Sulzer still more expensive than the Superior engine.

3.3 Update of Conceptual Design

The conceptual design section of the Phase I report has to be modified to take account of (1) the new choice of diesel engine, (2) the need for a fuel treatment system for #6 oil, and (3) the decision to place the system in a new location.

In Appendix 3B we give a detailed description of the two candidate #6-burning engines, Sulzer and Superior. The #6 oil engines differ from the #2-burning engine described in Phase I in requiring a #6 fuel treatment system and a separate set of #2 oil storage and day tanks for starting and stopping. The steam and electrical systems are the same for all engines. In Appendix 3C we present details of their performance, including heat balances at 100% and 50% loads. Engine performance deteriorates only slightly down to 50% load; it falls off rapidly for lower loads. Performance characteristics at 100% load are summarized in Table 3.3-1. Heat and electric outputs of both engines are similar. Because #6 oil is cheaper and is the fuel now used in the boiler system, the #6-burning engines have appreciably lower fuel costs, about 5.5 mills/kwh less than the #2-burning engine described in Phase I.

Table 3.3-1: Performance Characteristics of Diesel Engines

	<u>Sulzer</u>	<u>Superior</u>
Fuel	#6	#6
Maximum Electrical Output	1405 kw	1500 kw
Thermal Output	4.0×10^6 Btu/hr	5.3×10^6 Btu/hr
Low pressure steam	1.3×10^6 Btu/hr	2.5×10^6 Btu/hr
High pressure steam	2.7×10^6 Btu/hr	2.8×10^6 Btu/hr
Electrical Efficiencies	34%	31%
Thermal Efficiencies	39%	43%
Heat Rate	10,010 Btu/kw	11,060 Btu/kw
Incremental Heat Rate with Heat Credit	6,110 Btu/kw	6,260 Btu/kw

4. DESIGN PACKAGE

4.0 Introduction

The ICES has the following basic components: mechanical, including engine, generator, heat recovery, and fuel supply; electrical, including lights, motors, and grid connection; architectural; tie-in with utility system; noise and vibration control; and monitoring. We describe our preliminary design for each component briefly and refer to the appendices for more detail.

4.1 Mechanical

The major mechanical items are the diesel engine and generator, jacket heat recovery system, exhaust heat recovery system, fuel supply system, and fuel treatment system. Engine performance is described in Appendix 3C. The design, control and operation of the other mechanical systems are described in detail in Appendix 4A. Appendix 4A also gives key pressure drops showing that the system design is comfortably within manufacturers' tolerances.

Equipment lists including design criteria form Appendix 4B. Appendix 4C gives outline specifications for all major mechanical equipment.

4.2 Electrical and Grid-Connection

The electrical design has to meet the following demands: provision of adequate lighting to the new building under normal and emergency conditions, operation of motors for a large number of mechanical components, and compliance with Mass. Electric requirements for the grid-connection. The equipment needed to meet each of these demands is described, with outline specifications, in Appendix 4D.

4.3 Architectural

The architectural design has been constrained in two ways. First of all, it has to provide adequate space for all ICES equipment. Our equipment layout is shown in Fig. 4.3-1. Second, since the building must be located near the focal point of the campus, it must not intrude too much on the open space that is available, and its design must be compatible with the neighboring structures, including Jonas Clark Hall, the Goddard Library, and the new Goddard Memorial. We show a preliminary building design in Appendix 4E. A number of the Clark Trustees and other members of the Clark community felt that this building would not be satisfactory because of its mass, particularly

Figure 4.3-1

Equipment Layout

its height. The height of the building had been determined by the need to provide adequate clearance over the exhaust gas run shown in Fig. 4.3-1. We have recently ascertained that a straight exhaust run would be possible from either the Sulzer or the Superior engine at little or no additional cost. By lowering the waste heat boiler a corresponding amount we can save about 10 feet in the height of the building. The new height would then be approximately 10' above grade on the west side of the building and 20' above grade on the east side, an overall reduction in building volume of about 40%.

Since the new height is at the top of the indentation shown in Figures 4E-4 through 4E-7 in Appendix 4E, a new design for the building envelope is necessary. The Trustees feel, however, that a threshold has been crossed with the new dimension, and that it will be possible to make a new design that fits well into that part of the campus.

4.4 Utility Tie-In

Since the proposed Clark ICES is a retrofit onto an existing heating plant we have to take account of the existing heating, fuel, and water lines, and, in some cases, alter routings for these. The basic requirements are the following: steam from the jacket cooler must be tied to the existing 15 psig steam lines; steam from the waste heat boiler must be tied to the existing 125 psig lines; residual oil must be supplied to the diesel from the existing oil tanks. A new light oil fuel tank and distribution system must be supplied for starting and stopping the diesels. Details of the tie-ins are given in Appendix 4F.

4.5 Noise and Vibration

Noise and vibration are critical issues for the Clark ICES since the facility is to be located in the center of the Clark campus and since it will be in a building attached to Jonas Clark Hall, a major four-story classroom building. There are some helpful circumstances. Jonas Clark is a 90-year-old building with 18" thick brick walls, and the existing heating plant in the basement has had adequate noise and vibration isolation. Appendix 4G gives an outline of our considerations on noise and vibration. The present ICES design will meet our design objective of making no significant increase in ambient noise levels anywhere the campus is used.

4.6 Monitoring

We have made a preliminary determination of the type of monitoring that would be desirable in Phase VI. Subject to the recommendation and consent of DOE, our objectives are as follows.

(1) Monitor air pollution impact. Both the source emission of the boiler and ICES and ambient levels at Clark University are of interest. The Massachusetts DEQE currently samples

ambient particulate and SO_2 levels at Clark. Complete information would require the addition of ambient CO and NO_2 sampling, as well as source measurements of particulates, SO_2 , CO, and NO_2 . (Though O_3 is an air pollution problem, it cannot be simply related to sources and is thus not proposed for monitoring.)

(2) Monitor the heat of combustion of residual oil. The heat of combustion of residual oil varies widely. Accurate heat balance calculations require knowledge of this variation.

(3) Monitor chemical impurities in residual oil. Diesel engines are adversely affected by sodium and vanadium impurities in oil. To check whether our fuel treatment plant is working properly and to obtain accurate information on residual oil operating costs, it is important to measure these impurities on a routine basis before and after fuel treatment.

(4) Monitor performance of diesel engine. Long term system evaluation requires a continuous record of useful heat and electrical output of the ICES. This may be done by metering fuel and water feed lines.

(5) Monitor sector heat loads. Optimum load balancing between electric and heat loads requires knowledge of sector heat demand within the university. Sector heat demand may be measured by metering condensate return for six divisions of the University.

The preliminary cost estimate is given in Table 4.6-1.

Table 4.6-1: Monitoring equipment

Monitored variable	Method	Equipment Cost	Annual operating cost*
<u>Air pollution, ambient</u>			
particulates	periodic sampling by State	-	-
SO ₂	periodic sampling by State	-	-
NO ₂	periodic sampling by Clark	\$11,000	\$500
CO	periodic sampling by Clark	\$2,000	\$500
<u>Air pollution, source</u>			
particulates	periodic sampling by Clark	\$3,000	\$500
SO ₂	periodic measurement on fuel by Clark	-	\$500
NO ₂	periodic sampling by Clark	\$ 8,000	\$500
CO	periodic sampling by Clark	-	\$500
<u>Heat of combustion</u>	periodic measurement by Clark	-	\$500
<u>Engine performance</u>			
fuel use	Continuous metering of fuel	10,000	\$500
heat rate	Continuous metering of water feed line.		
<u>Sector heat load</u>	Continuous metering of condensate return from six heating sectors	\$17,000	\$500
<u>Fuel contaminants</u>	Monitoring vanadium and sodium content in oil, plus other heavy metals	2,000	500
<u>Sulfur content of fuel</u>	Monitor percent sulfur	-	500
Totals		\$53,000	\$5,500

* Operating cost is based on hiring students of analytical chemistry and physics to work under faculty direction.

5. FINANCIAL ANALYSIS

5.0 Introduction

In their November evaluation of the proposed ICES, the Clark Trustees agreed to the following investment criteria:

(1) The ICES should be 100% financed from savings, using an external source of capital.

(2) The expected payback period, including principal and interest should be 10 years or less.

(3) There should not be large risks associated with uncertainties in future economic conditions.

In November 1977 we showed that the proposed ICES met these requirements. At this writing, after a considerably more detailed analysis, and despite significant changes in some economic parameters, we confirm this conclusion.

We discuss capital and operating costs in the next two sections. In Section 5.3 we compare the ICES with the conventional system and show that the payback period is 9.4 years and the internal rate of return is between 14 and 15%. We also discuss the sensitivity of our model to various assumptions about key parameters, and conclude that the expected variations are acceptable: e.g. the extreme bounds of the payback period are 15 and 5 years, respectively. In Section 5.4 we discuss other features of the ICES which make it an attractive investment for Clark. In Section 5.5 we discuss the generalization of our results to other sites.

5.1 Capital Costs

Capital costs for two systems, the Sulzer 1405 KW_e engine and the Superior 1500 KW_e engine are summarized in Table 5.1-1. Detailed cost breakdowns are given in Appendix 5A. The total capital cost to Clark, beginning with phase III is \$1,460,000 for the Sulzer based system. In addition we expect to request DOE to fund the following demonstration capital cost items.

(1) Grid-connection at about \$41,000, as per the original RFP.

(2) Monitoring equipment at about \$53,000, as per the original RFP.

(3) Demonstration-related aspects of the power plant building, providing accessibility to the public, at about \$28,000.

(4) Fuel treatment system, at about \$95,000.

Table 5.1-1: Capital Cost Summary (\$1000s)

Item	Sulzer Engine	Superior Engine
Equipment and mechanical work	895	823
Civil Work	287	287
Electrical work without grid connection	60	60
Engineering costs	223	223
Total cost to Clark (proposed)	<u>1,465</u>	<u>1,393</u>
Grid Connection equipment	41	41
Monitoring equipment	53	53
Demonstration civil costs	28	28
Fuel treatment	95	95
Cost to DOE (proposed)	<u>217</u>	<u>217</u>

The first three are straightforward outgrowths of the present demonstration program. The fourth is discussed in more detail in Appendix 5A. We believe that fuel treatment should be considered a demonstration cost, at least in part, because sodium (accounting for most of the capital cost) is a regional problem only, and because there will be major economics of scale when use of heavy oils in engines becomes widespread. For example, a fuel treatment facility of ten times the capacity would only cost about twice as much.

5.2 Fuel and Maintenance Costs

Fuel costs with heat credit for the two candidate engines are evaluated in Table 3.3-1 and Appendix 3C. They are summarized in Table 5.2-1:

Table 5.2-1: Fuel cost and heat credit (mills/kwh)

Engine	Fuel cost	Heat credit	net fuel cost
Sulzer 1405 KW	25.0	9.7	15.3
Superior 1500 KW	27.7	12.0	15.7

We constructed Table 5.2-1 assuming that the price of #6 oil to Clark in 1980 would be \$2.50/10⁶ Btu.

Maintenance costs for the three engines are summarized in Table 5.2-2.

Table 5.2-2: Maintenance Costs

Item	Yearly Cost	
	Sulzer	Superior
Diesel engine	\$42,500	\$41,400
Fuel treatment	3,800	7,100
Miscellaneous	9,000	9,000
TOTAL	\$55,300	\$57,500
Cost per kilowatthour	5.6 mills	5.5 mills

The derivation of these cost estimates is given in Appendix 5B. The estimates include diesel manufacturer's recommended maintenance and cost experience, chemicals for fuel treatment, and safety margins. The miscellaneous items include the generator, waste heat boiler, fuel treatment system, pumps, etc. A detailed discussion of fouling of the waste boiler is given in Appendix 5B.

5.3 Comparison with the Conventional System

In Table 5.3-1 we list the base case assumptions we have made about costs which are used to compare the grid-connected ICES with the conventional system. We assume that the ICES is completed at the beginning of 1980, and that all costs including capital costs escalate at 6% per year from their values today. Because we assume a base cost of money of 6%, it does not matter when individual capital cost items are purchased.

In Table 5.3-2 we list the energy output of the ICES, appropriately divided into Clark usage and Clark sales. These numbers are taken from the energy outputs described in Section 3.1. With this we may compare the costs of the ICES with conventional system costs, as shown in Table 5.3-3. It is seen that the Sulzer system has a first year operating savings of \$162,000, and a net savings after payment of financing costs of \$20,000. By the tenth year these savings project to approximately \$240,000 and \$100,000 respectively in constant 1980 dollars. The present estimates are little different from those obtained in November, as shown in Fig. 5.3-1.

We have examined the sensitivity of the projected savings to the values of our base case parameters. In Table 5.3-4 we list the key parameters and the sample variations we have used to test the sensitivity of the savings. Figure

Table 5.3-1: Base case assumptions (1980 start-up)

Variable	Value
Rate of inflation	6%/yr
Price of fuel (anticipated)	
#2 oil	\$3.00/MBtu
#6 oil	\$2.50/MBtu
Prices of electricity (anticipated)	
Purchased by Clark	4.7¢/kwh
Sold by Clark, weekdays 7 A.M. - 11 P.M.	2.7¢/kwh
Sold by Clark, other	2.4¢/kwh
Distribution capacity charge:	
first year:	\$18,000
after 5 years:	\$36,000
Retail rate structure multiplier	1.2
Plant lifetime	20 years
Clark electric demand	6.9×10^6 kwh/yr
Conventional boiler efficiency	75%

Table 5.3-2: Electricity and Thermal Outputs

ELECTRICITY

1. Clark total demand	6.9×10^6 kwh
2. Clark demand supplied by diesel	6.5×10^6 kwh
3. Clark demand supplied by purchases	0.4×10^6 kwh
4. Diesel-produced energy sold to utility	4.6×10^6 kwh
5. Total production by diesel	11.1×10^6 kwh
6. Maximum possible production by diesel	12.5×10^6 kwh
7. Capacity factor	90%
8. Outages for maintenance and certain summer nights	6%
9. Operation at de-rated power level (average 65% full load)	8%

HEAT

10. Clark total demand	11×10^{10} Btu
11. Clark demand supplied by diesel	3×10^{10} Btu

FUEL SAVINGS

12. Savings at Clark plus savings at utility due to reduced generation	4×10^{10} Btu
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Table S.3-3
FIRST YEAR (1980) BASE CASE CALCULATION

	<u>Sulzer Engine</u>
A. Capital Cost	\$1,650,000
B. Interest Rate	6%
C. Annual Capital Cost (\$K)	141,000
D. Annual Fuel Cost	278,000
E. Annual O & M	70,000
F. Annual Heat Credit	108,000
G. Operating Cost (D + E - F)	240,000
H. Conventional Electricity Cost	326,000
I. Clark Sales	114,000
J. Purchases	38,000
K. Total Credits (H + I - J)	402,000
L. Net Operating Savings (K - G)	162,000
M. Net Savings (L - C)	21,000
N. Payback (years)	9.4
O. Internal Rate of Return	14.5%

Fig. S.3-1: Base case net savings expressed in constant and current dollars.

5.3-2 shows the variation of the Sulzer engine savings with each of the changes. The total variation is taken to be the square root of the sum of the squares of each individual variation. The savings are always positive, even the total variation; hence the risk inherent in the ICES investment appears acceptable.

Table 5.3-4: Sensitivity Analysis

Key parameter	Base value	Variation tested
Efficiency of Clark Boiler	0.75	0.85
Interest rate on loan	0.06/yr	0.03 - 0.07/yr
Retail rate structure multiplier	1.2	1.35
rate of fuel price escalation	0.06/yr	0.0 - 0.12/yr
Additional credit for import	0	0.3 ¢/kwh
Mis-estimate of capital costs	0	±\$200,000
Inflation rate	0.06/yr	0.03 - 0.09/yr

5.4 Evaluation of Investment

The anticipated 15% internal rate of return with the reasonable assurance of positive net savings is enough to make the grid-connected ICES an attractive investment for Clark. In addition, as pointed out by the University business officer, L. Landry, the investment in the ICES is a hedge against the inflation of energy costs. If about half

of the electricity generation costs are fixed as capital costs, only the remaining half are subject to inflation. Thus the costs using the ICES will rise much more slowly than costs for the conventional system as oil prices go up. Of course, costs would decline less rapidly if oil prices dropped, but we consider that much less likely. Furthermore, by generating most of its electricity, the University would be almost completely insulated from unfavorable changes in electricity rates. It is certain that electricity rates will change in the next year, as the DPU has required utilities to introduce time-of-day rates. It is not certain that the changes will be unfavorable to Clark, but it is likely. The University now benefits from sharply declining block rates and there is both state and federal pressure for flattening rate structures. Furthermore, the University does not have much flexibility for shifting more electric use to the nighttime and so it could be hurt by very high peak rates.

Fig. 5.3-2: Sensitivity of savings for the Sulzer engine burning #6 oil. Base case is shown as solid line, variation by dotted line. The variation used is defined in Table 5.3-4.

Thus we consider the ICES an attractive investment on two grounds. It offers a decent rate of return with only modest risk, and it helps protect the University from potential unfavorable changes in energy prices. Along with these benefits Clark would benefit significantly from being a demonstration site. The demonstration would give Clark national visibility and would give a major boost to our research and teaching in energy studies.

5.5 Generalization to other sites

The analysis of the previous two sections shows that the proposed ICES is a reasonable investment for Clark University at this point. It is interesting to consider how important the DOE contribution is to this conclusion. There are two aspects to this question. (1) How big an effect does the DOE contribution have on the economic evaluation of the proposed plant? (2) How significant has DOE sponsorship been in attacking and removing institutional barriers, and other first-of-kind costs?

Our estimate, given in Appendix 5A, is that Clark's base capital cost is only \$30,000 to \$125,000 lower than the cost to a similar facility planning to duplicate the Clark system. Because of Clark's unusual architectural needs Clark's base capital cost is \$100,000 to \$200,000 less than it would cost Clark to design and build the plant without DOE participation. All of these numbers are within the range of uncertainty of capital costs considered in our sensitivity analysis.

The answer to the second question is that DOE participation has been essential to Clark's resolution of most institutional issues, and hence Clark's willingness to continue the project. We have repeatedly found in dealing with Massachusetts Electric, with the Department of Public Utilities, with the Attorney General, and most recently with the Department of Environmental Quality Engineering that Clark's case represented a first-of-a-kind test case. It is quite clear that under these conditions the Clark trustees would soon have lost heart had it not been for the support of DOE. In addition it is unlikely that Clark would have been prepared to make extensive engineering comparisons of alternative systems before knowing that the project was feasible, yet these comparisons were essential in finding the most suitable configuration for a facility like Clark.

Assuming, then, that the Clark ICES is built, we believe that a number of important precedents will have been established which will make the installation of subsequent facilities considerably easier. The technical comparison of

system alternatives can be applied with minor alterations to a large number of facilities resembling Clark, and Clark's experience in negotiating a contract with our electric utility, and coping with environmental and legal obstacles, will at least suggest a number of short cuts. We hope to make the Clark ICES even more useful by carefully documenting its performance, its impact on the utility and its environmental effects.