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A PRELIMINARY FEASIBILITY STUDY OF A
GRID-CONNECTED INTEGRATED COMMUNITY
ENERGY SYSTEM AT CLARK UNIVERSITY

Volume 2. Report and Appendices

August 1977

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

MASTER

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GRID-CONNECTED INTEGRATED COMMUNITY ENERGY SYSTEM AT CLARK UNIVERSITY

Volume II

REPORT and APPENDICES

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August, 1977

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INTRODUCTION

We have made a four month study of the feasibility of grid-connected cogeneration at Clark University. We present here a summary of our results.

Summary of Task Accomplishments of Phase I

Energy and economic analysis. Clark's energy need and use profiles were compared with theoretical and actual grid-connected cogeneration systems. We concluded that the most useful system for Clark would be an ebulliently cooled diesel of 1500 kw, burning #6 oil, and supplemented by Clark's existing boilers. The most favorable production model found to date is a Fairbanks-Morse 1500 kw diesel burning #2 oil, costing \$800,000 installed, and giving oil savings of 19% a year and an internal rate of return of 18% a year.

Institutional problems. We have been assured by officials responsible for enforcing environmental, zoning, building, and other codes and regulations that the proposed ICES poses no serious problems and will probably proceed to approval without delay once final design is available. We have also investigated the restrictions of the University Charter and, though some problems remain to be resolved, we do not anticipate any difficulty.

Conceptual design. We have considered two possible locations for the cogeneration system, one in an existing building that now houses the university's boiler, the other in an external addition to this building. Both sites appear feasible. We have also made process flow diagrams and system schematics for the principal components of candidate ICES systems and have uncovered no fundamental difficulties in linking with the existing heat distribution system of the university.

Firming up commitments. The New England Electric System has agreed to purchase electricity from Clark for a price closely approximating the marginal cost of displaced fuel. This is currently about 2.4¢/kwh on weekdays and 2.0¢/kwh on weeknights and weekends. When we import power we will pay the present posted rate of about 4.2 to 4.5¢/kwh. There will be no restriction on interchange.

The most attractive financing would be a federally guaranteed low interest loan like the 3% loans in HUD programs for energy conservation

in academic institutions. If President Carter's energy program goes into effect there will be other loans of this type, and there may even be some matching grants. HEFA bond issues also offer a good possibility. Because of restricted standard lines of credit, we are reluctant to borrow against our limited endowment.

The Trustees of Clark University have passed a resolution affirming their enthusiasm for and intention of following through with the demonstration project and directing the Treasurer and Dean to make the necessary arrangements.

Work management plan. We have made detailed estimates for the effort required, the cost, and the duration of tasks in remaining phases of the demonstration program. We expect that Phase II, detailed feasibility and preliminary design, will last about 9 months including reporting requirements and will cost about \$219,000. We then anticipate a two-year period before startup during which the greater part of program costs will be borne by the University. ERDA will be asked to support design and procurement of equipment for the grid-connection and monitoring, as well as the continuing evaluation of the program and the associated information program.

Recommendation: Request for Continuation of Clark
as Demonstration Community

Clark University is attractive for an ICES demonstration.

Clark University is willing and able to proceed with the development of an ICES demonstration.

The Fairbanks-Morse Colt 4 cyl. 2160 BHP 1530 kw diesel generator fills nearly all the objectives set for an ICES project at Clark at a cost of less than \$1,000,000.

Therefore we recommend that Clark University be chosen to continue this study into Phase II. Here are some additional reasons.

Transferability of results. Clark is typical of a large number of Northeast communities, both in size and energy use. Clark also represents a typical example of retro-fitting. Since retro-fitting is the only way ICES can become widespread in the U.S. in the next ten years, Clark's experience should be of maximum benefit as a model.

Monitoring, evaluation and training. Clark is a center for energy

studies and has resources in faculty and students and staff with appropriate experience for long-term monitoring and evaluation of the proposed ICES system. From Clark's point of view, our selection as a demonstration site will give a boost to our energy-related studies by providing a full-scale laboratory for students and faculty.

Dissemination of results. Clark faculty members customarily present research results in technical publications and conferences and are experienced in the art of such communication. We are therefore able to offer a substantial information program in connection with the proposed ICES demonstration. This program will include press releases, site visits by the general public, performance data sheets for technical audiences, a planning workbook for potential new ICES users, publication of system evaluation in standard journals and at scientific conferences, and intimate links to a Massachusetts State Planning study on cogeneration. Two papers on the project have already been accepted for presentation at national and international conferences.

Grid connection. We have successfully negotiated a very favorable preliminary agreement for electric interchange with the New England Electric System, as noted above.

Economic viability. Candidate ICES offer internal rates of return of 15-25% compared with Clark's conventional energy system. The range is due to difference between engine makes and models as well as uncertainties in final costs.

Cost to ERDA. Because the expected rates of return are sufficiently high for Clark to finance the basic system itself, we plan to ask ERDA support for only those costs listed in the original request for proposals.

Energy savings. The proposed ICES will reduce by approximately 25% Clark's direct and indirect consumption of energy. This large saving is due to the planned use of diesels, and is especially significant because New England depends almost wholly on foreign oil for its energy supply.

Firmness of commitment. The Trustees of Clark University, who are ultimately responsible for the operation of the University, have recently passed the following resolution:

As Trustees of Clark University we have reviewed the

proposed cogeneration demonstration project. We expect that the demonstration project will involve an investment of approximately \$1 million with a projected internal rate of return of about 20%. We also recognize that the project offers Clark an unusual opportunity to strengthen energy-related academic studies and thus to achieve prominence in the field of energy innovation. We are therefore enthusiastic about the proposed demonstration program and are prepared to follow through on the project to become a demonstration community. Our decision assumes Phase I results will be confirmed in Phase II, and that suitable financing can be arranged. We therefore instruct the Treasurer, Mr. Landry, and the Dean of Academic Affairs, Mr. Puffer, to initiate application for Phase II of the Program, and to make the necessary preliminary contractual arrangements.

1. PRELIMINARY ENERGY AND ECONOMIC ANALYSIS

1.0 Introduction

The goal of this chapter is the identification of candidate ICES which are economically attractive and energy saving. In Section 1.1 we consider those site characteristics that affect the integration of the ICES into the existing energy plant. In Section 1.2 we report the scope and results of a monitoring program through which we have defined heat and electric demand profiles for Clark University. Section 1.2 also contains service demand profiles and a brief discussion of some unexpected byproducts of monitoring which should lead to more efficient energy use independent of the ICES. In Section 1.3 we discuss projected growth of the university. In Section 1.4 we describe the economic aspects of the existing energy system, and emphasize the great uncertainties that prevail in the area of oil prices and rate structure. In Section 1.5 we conduct energy and economic comparisons of 14 candidate ICES and arrive at the conclusion that the system of choice is an ebulliently cooled diesel, burning #6 oil, and rated at approximately 1500 kW. For economic comparisons we use a ten-parameter evaluation model which specifies annual savings for each of the candidate systems and also characterizes each in terms of an internal rate of return. For energy comparisons we utilize detailed heat and electric specifications as supplied by the manufacturer.

1.1 Site Characteristics

Clark University has the character of a mixed commercial and residential facility. Major building uses include housing, academics, administration, dining, theatre, student activities and stores. Except for a small amount of electric heating where temperature control is critical, heat for the entire Clark campus is supplied by a central boiler plant through a steam distribution system. Distribution steam pressures range from 15 to 125 psig, as shown in Fig. 1.1-1. Electrical power for the campus is supplied at 13.8 kV at one point (Goddard Library), and is distributed and transformed at voltages ranging from 13,800 to 208 V, as shown in Fig. 1.1-2.

The single access point for utility power will make a potential grid connection a straightforward matter. In contrast, the range of pressures used for steam distribution raises certain problems in the design of an appropriate ICES. Basically we must ask to what extent is by-product heat from an ICES system available in a form matched to the characteristics of the existing steam distribution system, or, alternatively, by what modification of the distribution system and at what cost can the heat output of a candidate ICES be fully utilized? Key aspects of the problem are summarized in Table 1.1-1.

Table 1.1-1. Form of by-product heat and end use

Form of by-product heat	Source of heat	End use
125 psig steam	steam turbine gas turbine exhaust of diesel	End use is unlimited without modification of distribution system.
15 psig steam	jacket of certain diesels	End use limited to present 15 psig lines, having steam load in range of 2500 lb/hr.
180°F water	jacket of certain diesels	End use not possible without distribution system modification. (v. Table 1.1-2)

From this we come to a three-part analysis of the heat-matching problem, as follows.

- (1) Steam and gas turbines present no problems since the use of

Fig. 1.1-1. Steam distribution system at Clark University. Steam lines in all cases include both steam supply and condensate return.

Fig. 1.1-2

ELECTRICAL UNDERGROUND SYSTEMS ON CAMPUS

—————	13800	Volts	3	phase
-----	4160	Volts	3	phase
.....	480	Volts	3	phase
-----	208	Volts	3	phase
o	Manholes			
T	Transformer Locations			

1. Downing Administration Center	15. Hughes Hall
2. Atwood Hall	16. Florence Residence
3. Academic Center	17. Student Activities Center
4. Geography Building	18. General Store/Birth Control Center
5. Jefferson Hall	19. Wright Hall
6. Alumni Gymnasium	20. Little Center for the Visual and Performing Arts
7. Science (Bio-Physics) Building	21. Dodd Hall
8. Jeppson Laboratory	22. Johnson Hall
9. Jonas Clark Hall	23. Sanford Hall
10. Robert Hutchings Goddard Library	24. Estabrook Hall
11. Bullock Hall	25. Physical Plant
12. Potter Laboratory	
13. Dana Commons	
14. Dana Dormitory	

125 psig steam is essentially unlimited. Heat recovery from diesel exhaust presents no problems for the same reason.

(2) The use of 15 psig steam from diesel jackets is limited by the presently available 15 psig distribution network. If significant heat waste is to be avoided, this places a size limit on candidate diesel ICES. For some diesels such as the Fairbanks Morse and Sulzer models jacket cooling is ~30% of the total usable heat output and the size limit is ~3 MW; for other diesels which provide as much as 60% of the total usable heat output in the jacket, the size limit is ~1.5 MW.

(3) Use of 180° water from diesel jackets requires modifications of the distribution system in all cases. These are in general excessively costly. To illustrate, we indicate in Table 1.1-2 the cost and payback of the three most likely conversions.

Table 1.1-2. Cost of building conversion required for use of 180°F jacket cooling water for heating

Building	Max. Load (10 ⁶ Btu/h)	Avg. Load (10 ⁶ Btu/h)	Heating Cost (\$/yr)	Building Conversion (\$)	Internal Rate of Return
Jonas Clark	3.35	0.84	21,300	502,000	<5%
Geography	1.98	0.5	12,300	186,000	8%
Academic Center	1.35	0.35	8,600	60,000	18%

We have therefore limited ourselves in the subsequent analysis to consideration of steam turbines, gas turbines and ebulliently cooled diesels.

1.2 Energy Profiles

In this section we report on the results of our monitoring program and derive from them aggregate heat and electric demand profiles. We then present information on individual building heat demand and heat and electric service demands. In contrast to aggregate demands, these can not be directly based on monitoring data, and are therefore less certain. In our analysis of service demands we find that non-building services are a negligible fraction of total energy demand.

As a byproduct of our monitoring effort, we make observations that

have important implications for improving energy efficiency through improved heating controls.

1.2.1 Extent of monitoring effort

In order to refine our understanding of fuel and electric usage at Clark University we began a monitoring program, the principal aspects of which are described in Table 1.2.1-1. A diagram of the monitoring system appears in Fig. 1.2.1-1. Although serious delays were caused by late instrument delivery and failure of water flow gauges, we were able to obtain significant results as follows.

(1) The efficiency of the largest of our existing boilers was measured under varying load conditions. (See Fig. 1.2.1-2.)

(2) The University heat use as a function of degree days was measured. (See Fig. 1.2.1-3.)

(3) Temperature difference of $\sim 4^{\circ}\text{F}$ between Clark and Worcester Airport Weather Station was determined. (See Fig. 1.2.1-4.)

(4) Typical diurnal variation of total electric demand was recorded. (See Fig. 1.2.1-5.)

(5) During periods when the entire university was supplied by the #3 boiler typical diurnal variation of total heat demand was recorded. (See Fig. 1.2.1-6.)

The principal shortcoming of the monitoring program to date is that individual building energy profiles are not directly measured, but must be estimated using standard computational methods of dubious validity (see below). Hence, a logical extension of the monitoring effort would be hourly measurements of steam demands in each of the 21 major buildings of the campus, and correlation of this information with weather.

For more detail on the monitoring effort, see Appendix 1A.

1.2.2 Aggregate electric demand profile

Using results from the monitoring program we developed an electric load distribution curve covering the period of one year. We adjusted this curve to take into account three sources of load increase which will come into effect before installation of the proposed ICES: (a) lighting

Table 1.2.1-1. Summary of energy monitoring effort

Variable monitored	Method	Sampling frequency	Accuracy	Period of Survey	Comments
University fuel consumption	manually read oil tank float	3/day	250 gal.	Nov. 30, 1976-Present	
University electric consumption	automatically recording KW-meter	continuous	10 kW	Sept. 1974-Present	
Local weather	automatically recording thermometer *	6/hr	0.1°C	April 8, 1977-Present	Experienced late instrument delivery
#3 boiler oil consumption	automatically recording oil flow meter *	1/hr	10 gal.	March 14-Present	
#3 boiler steam production	automatically recording make-up water meter *	1/hr	800 lbs.	March 14-Present	Experienced repeated equipment failure

* Equipment purchased with ERDA funds

Fig. 1.2.1-1: Diagram of monitoring system

Fig. 1.2.1-2: Measured boiler efficiency as a function of feedwater intake.

Fig. 1.2.1-3: University heat use as a function of degree days

Fig. 1.2.1-4: Temperature difference between Clark and Worcester Airport

Fig. 1.2.1-5: Typical diurnal variation of electric demand

Fig. 1.2.1-6: Typical diurnal variation of oil demand and outside temperature

and ventilation in the new student activities center; (b) use of supplementary electric heat pumps in the new student activities center; (c) an anticipated increase in summer use of the campus, leading to increased air conditioning. Our estimate is that these effects will increase electric consumption by 15%. The resulting electric load distribution is shown in Fig. 1.2.2-1.

1.2.3 Aggregate heat demand profile

Compared to the electric case, extracting heat demand profiles from the monitoring data is somewhat more complex and consisted of four steps as follows.

(1) Using an average boiler efficiency of 0.75 (v. Section 1.2.1), the data on fuel use was converted to steam demand vs. degree days. In this a distinction was made between four cases: (i) regular session weekdays; (ii) regular session weekends; (iii) vacation weekdays; and (iv) vacation weekends.

(2) Using 30-year-average weather data, demand profiles were generated for each of the four conditions defined above. These were, of course, limited to the heating season.

(3) Using monthly gas and oil consumption for the summer, a boiler efficiency of 0.75, and estimated variations in daily summer steam demand, approximate demand profiles were generated for the summer. (The absence of monitoring data for the summer made this estimate necessary.)

(4) The results of (2) and (3) were aggregated to obtain a yearly steam demand profile. To account for the new student activities center and anticipated increased summer usage of the campus, this profile was increased point by point by 15%. The result appears in Fig. 1.2.3-1.

1.2.4 Building service demands

As already noted, to obtain heat service demands for individual buildings we were forced, in the absence of direct measurements, to rely on calculations. These can be described as follows.

(1) Peak thermal demands for individual buildings were found by Fitzmeyer and Tocci using ASHRAE recommendations.

(2) It was assumed that division of actual use among buildings is

Fig. 1.2.2-1: Electric Load Distribution

proportional to estimated maxima described above.

The results of this procedure are summarized in Table 1.2.4-1. Because estimated peak total thermal demands are 1.5 times the measured peak total thermal demand obtained from the monitoring program, we are quite skeptical of these estimates and believe it essential to make direct measurements of building heat demands.

Table 1.2.4-1. Heat demand of principal buildings

Building	Gross ft ²	lbs. steam pressure	ASHRAE calculated peak demand (lbs/hour)	Our esti- mated actual peak demand (lbs/hour)
1. Jonas Clark	84,289	Varied	3,350	2,244
2. Atwood Hall	23,567	12	1,750	1,172
3. Science Bldg.	40,843	40	2,550	1,708
4. Geography Bldg.	27,453	Hot water	1,350	904
5. Jefferson Hall	24,347	40	1,800	1,200
6. Alumni Gymnasium	24,366	40	2,400	1,600
7. Goddard Library	137,000	125	6,000	4,000
8. Jeppson Lab	33,164	40	3,300	2,200
9. Bullock Hall	34,990	125	2,270	1,513
10. Wright Hall	41,894	125	2,500	1,666
11. Estabrook Hall	26,651	12	1,400	933
12. Administration Bldg.	24,593	12	1,350	900
13. Little Commons	19,604	125	1,080	720
14. Sanford Hall	40,993	125	2,500	1,666
15. Johnson Hall	42,193	125	2,540	1,693
16. Dana Commons	23,100	125	1,160	773
17. Hughes Hall	35,920	125	2,160	1,439
18. Dana Dorm	37,222	125	1,860	1,240
19. Academic Center	43,954	Hot water	1,980	1,320
20. Dodd Dorm	33,293	125	1,665	1,110
21. Student Act. Center	65,000	125	2,700	1,800
22. New apartment			1,000	667
TOTAL			48,665	32,468

Service demands, expressed as percent of total heat demand, have been calculated as shown in Table 1.2.4-2. These include demand modifications as outlined in Sections 1.2.2 and 1.2.3.

To obtain electric service demand we have used ratings of some equipment and estimates provided by physical plant personnel. These include demand modification as outlined in Section 1.2.2 and 1.2.3. The results of

our analysis appears in Table 1.2.4-3.

Table 1.2.4-2. Heat service demands, including hot water

Service	Projected demand with new services installed (% of total demand)
Space heat	
Academic	26
Housing	33
Administration	4
Student activities	12
Domestic hot water	
Academic	3
Housing and dining	15
Administration	1
Student activities	6
Total	100

Table 1.2.4-3. Electric service demands

Service	Projected demand with new services installed (% of total)
Space heat	
Administration	5
Student activities	5
Lighting	
Buildings	59
Outside	2
Ventilation	10
Cooking	19
Total	100

1.2.5 Byproduct of monitoring

Examination of Fig. 1.2.1-6 shows a two-hour lag between outside

temperature changes and oil consumption. This has the effect of producing "overshoot" in oil consumption, which in principle is avoidable. The reason for the slow response and consequent overshoot of oil consumption is the heat storage capacity of the university. If these overshoots are removed through suitable redesign of controls, we estimate that considerable oil savings are possible.

In addition, it has been possible to deduce the time dependence of the average inside temperature for the university using the aggregate monitoring data described in Section 1.2.1. This indicates that, despite efforts to the contrary, there is no significant "turn-down" of temperature during night-time. (A typical result appears in Fig. 1.2.5-1.) Consequently, independent of overshoot, additional significant oil savings are possible.

The university is investigating both of the above possibilities for additional oil savings.

1.3 Projected Growth

No significant growth in Clark facilities or in energy demands is anticipated after completion of the gymnasium and augmentation of the summer schedule. Both of these effects were estimated in 1.2 since they will precede installation of the ICES.

We have concluded that it is neither feasible nor desirable for Clark to try to sell heat to its neighbors. The distribution system would be prohibitively expensive, it would not improve our load factors, and there are serious political problems.

1.4 The Conventional Energy System

Heating and Cooling. Clark's existing space and hot water conditioning system is largely powered by a boiler plant producing steam in the range of 15 - 125 psig pressure. The plant burns #6 fuel oil and can burn gas when available. End use equipment includes steam radiators, pressurized hot water radiators, hot water, and absorption air conditioning. Current steam demand, as already indicated, peaks at 32,000 lbs of steam per hour; average fuel use is 1.2×10^{11} Btu/yr.

Electric Power. Clark currently buys power from Massachusetts Electric

Fig. 1.2.5-1: Variation of deduced inside temperature, indicating absence of night-time turndown.

Company, a member of the New England Electric System. A single utility line enters the campus at a voltage of 13,800 volts. After metering, power is distributed by Clark-owned transformers and lines to the campus. Major electric end-use equipment (v. Section 1.2.4) includes lighting, ventilation and cooking. Peak electric demand is about 1.5 MW; average annual use is 6.6×10^5 kwh/year.

1.4.1 Present prices

Since our original proposal there have been no significant changes in the provisions under which Clark buys fuel and electricity; however prices have changed markedly, as shown in Table 1.4.1-1. The electricity rate schedule is shown in Appendix 1B. The effects of these price increases are largely traceable to recent increases in the price of oil and imply an added \$117,000 in Clark's annual energy bill.

Table 1.4.1-1. Energy prices at Clark University

Commodity	Price (11/76)	Price (5/77)
Electricity	3.6¢/kwh average	4.2¢/kwh average
#6 Fuel Oil	\$1.87/10 ⁶ Btu	\$2.50/10 ⁶ Btu
#2 Fuel Oil	\$2.35/10 ⁶ Btu	\$3.00/10 ⁶ Btu
Natural Gas		
Contract basis	\$2.55/10 ⁶ Btu	\$2.62/10 ⁶ Btu
Interruptible	\$1.48/10 ⁶ Btu	\$1.92/10 ⁶ Btu

1.4.2 Projected prices

Projected prices of heating oil and electric power at Clark depend significantly on future prices of oil, the extent of nuclear power development by the utility, and the electric rate structure mandated by regulatory agencies. It is beyond the scope of this report to make a detailed analysis of these factors. We therefore limit ourselves to the following observations.

Oil prices. The historical record, shown in Fig. 1.4.2-1, indicates very rapid changes, and of itself discourages projections. A belief in the stability of world trade and politics over the next ten years leads to the conclusion that oil will escalate no less than general inflation, which we judge to be 6% per year.

Rate structure. The historical record, shown in Fig. 1.4.2-2, indicates

Fig. 1.4.2-1: Historical record of utility oil prices and the 6% projection used in the present study.

Fig. 1.4.2-2 Historical record and base case projections of wholesale distribution costs and the retail rate structure for Clark. Also shown are the retail rate structure factor for the small consumer and the retail rate structure factor for the proposed flat rate structure.

a declining ratio between Clark electric costs and utility wholesale costs. This might be expected in a situation in which fuel costs dominate generating costs. At the same time, Clark's rate structure factor is far removed from the one applied to small consumers and considerably below a rate structure factor applicable in the case of flat rates. Given present consumer campaigns and Presidential efforts in the direction of flatter rate structures, we think that conservative planning leads us to expect an increase in the rate structure factor for Clark, leading to correspondingly increased prices independent of escalation.

Utility generating costs. The historical record, shown in Fig. 1.4.2-3 indicates rapid change because of the domination of oil fired generation in New England. In the future, utility costs will include increasingly large contribution from nuclear power, especially in the form of capital costs. In a separate study, conducted prior to the present contract (STS Review, Vol. 2, #3, Clark University, 1976), we have shown that the installation schedule for nuclear power anticipated by NEES will not significantly reduce the escalation of electricity prices even though oil burning plants are in part replaced. We therefore have good reason to project electric utility generating costs at least at the general inflation rate.

To summarize, Clark can expect to experience energy prices that escalate at 6% or faster. We have found no credible mechanisms by which increases would be less rapid than general inflation.

1.4.3 Physical character of fuel

Because of its possible relevance to the choice of engine, we summarize the physical properties of the fuel used in the Clark boiler plant in Table 1.4.3-1

1.5 Candidate ICES: Energy and Economic Comparisons

In this section we indicate how we arrive at our system of choice: a single, ebulliently cooled diesel having a maximum electrical output of 1500 kW, and satisfying about 1/3 of Clark's average steam demand. Though our analysis was quantitative throughout, as will be seen below,

Fig. 1.4.2-3: Utility cost of electric power

Table 1.4.3-1. Typical no. 6 oil currently
being burned in heating boilers
(data from Northeast Petroleum)

Specific Gravity (API at 60°F)	20
Viscosity (S.S.C. @ 122°F)	25.2
Pour Point (°F)	40 ave., 59 max.
Flash Point (°F)	166 - 200
Sulphur (%)	.94 - .95
Water and Sediment (%)	.10 - .20
Vanadium (ppm)	30 - 52
Sodium (ppm)	12
Ash (%)	.04 - .05
Heating Value (Btu/lb)	18,924

it is possible to describe our decision process qualitatively as follows.

(1) At the outset, we considered three general types of systems: steam turbines, gas turbines and diesels. Of the three, gas turbines could be eliminated in all cases because of low electric efficiency, high maintenance cost, and expensive fuel.

(2) Next, we considered steam turbine and diesel systems that can in principle meet all of Clark's steam demand. Because steam demand is sharply peaked, and because it is impractical to export excess steam, all such systems would run most of the time at half capacity or less (see Fig. 1.2.2). This ruled out steam turbines because they produce essentially no electricity at half capacity, and it also ruled out diesels because of unused capital investment.

(3) Next we considered steam turbines and diesel systems that were sized at half or less of Clark's steam demand, and which would require backup by Clark's existing boiler facility. In this case, the problem of underutilized capacity is avoided; however, steam turbines of this size have such small electric output that they failed on economic grounds. Diesels, on the other hand, showed reasonably large returns, especially if their size was reduced to a point that no significant dumping of heat was required during periods of low university heat demand. The size range for which this is true roughly defines the system of choice: a 1500 kW diesel. The requirement that this diesel be ebulliently cooled arises from the fact that, as indicated earlier, the university has no way of utilizing hot water without large distribution system modifications.

It is interesting that our system of choice also has rather handsome fuel savings when compared to steam turbines of various kinds. This is again because steam turbines that are compatible with our steam demand profile produce negligible amounts of electricity.

In the following sections we provide details that support the qualitative arguments we have made.

1.5.1 Economic evaluation model

In order to obtain an estimate of the economic merits for a given ICES we used a simple algebraic model that describes the savings attainable with

a given system when compared to the conventional energy system. We give the essential features below. It is not essential to follow the model in detail in order to understand the remainder of the discussion.

The annual (dollar) savings for Clark of an ICES can be written in current dollars as:

$$S(t) = Y(t) - I(t) \quad (1)$$

where

t = time in years.

$S(t)$ = the annual savings as a function of time.

$Y(t)$ = the cost of providing all of Clark's energy needs with the conventional system.

$I(t)$ = the cost of providing all of Clark's energy needs with the ICES installed minus a credit for electricity exported.

The conventional system costs include payments for electricity to the utility, and capital, fuel and maintenance costs for the Clark boiler system. Thus we write

$$Y(t) = u_r(t)Q_t + F_b(t) + C_b + M_b(t) \quad (2)$$

where

$u_r(t)$ = the retail price of electricity in \$/kwh.

Q_t = Clark's total annual electric demand in kwh.

$F_b(t)$ = Clark's annual boiler fuel cost in \$.

C_b = Clark's annual boiler capital cost in \$.

$M_b(t)$ = Clark's annual boiler maintenance cost in \$.

Similarly

$$I(t) = C_i + M_i(t) + F_i(t) + C'_b + M'_b(t) + F'_b(t) + u_z(t)Q_z + Z - u_s(t)Q_s - u'_s(t)Q'_s \quad (3)$$

where

$M_i(t)$ = ICES annual maintenance costs, \$.

C_i = ICES annual capital costs, \$.

$F_i(t)$ = ICES annual fuel costs, \$.

- C'_b = Boiler annual capital cost, boiler operated as backup, \$.
 $M'_b(t)$ = Boiler annual maintenance cost, boiler operated as backup, \$.
 $F'_b(t)$ = Boiler annual fuel costs, boiler operated as backup, \$.
 $u_z(t)$ = retail price of electricity purchased on standby basis, \$/kwh.
 Q_z = Annual demand for standby electricity, kwh.
 $Z(t)$ = Annual charge for standby in excess of rate charge.
 $u_s(t)$ = price of electricity sold to utility, \$/kwh, peak periods.
 $u'_s(t)$ = price of electricity sold to utility, \$/kwh, off peak periods.
 Q_s = quantity of electricity sold annually to utility, kwh, peak.
 Q'_s = quantity of electricity sold annually to utility, kwh, off peak.

We assumed that installing the ICES and reducing the use of the Clark boiler does not alter the capital and maintenance costs of the boiler. This means

$$C_b(t) = C'_b(t); M_b(t) = M'_b(t) \quad (4)$$

We also assumed that the rate charged by the utility for standby electricity is the same as in the conventional arrangement, and that higher unit costs for standby are absorbed in the standby charge, $Z(t)$. This means

$$u_r(t) = u_z(t) \quad (5)$$

With these simplifications Eqs. (1-3) combine to yield

$$\begin{aligned}
 S(t) = & u_r(t)Q_t + F_b(t) - C_i - M_i(t) - F_i(t) - F'_b(t) \\
 & - u_r(t)Q_z + u_s(t)Q_s + u'_s(t)Q'_s - Z(t)
 \end{aligned} \quad (6)$$

In order to provide further simplification of this result, we introduce unit fuel, maintenance and capital costs for the ICES, expressed as \$/kwh. (An equivalent method is to express everything in \$/Btu.) Accordingly, the unit fuel cost is

$$f(t) = [F_i(t) - (F_b(t) - F'_b(t))]/Q_i \quad (7)$$

the unit maintenance cost is

$$m(t) = M_i(t)/Q_i \quad (8)$$

and the unit capital cost is

$$c = C_i/Q_i \quad (9)$$

where

$$Q_i \equiv Q_s + Q'_s + (Q_t - Q_z) \quad (10)$$

is the quantity of electricity produced by the ICES. With these simplifications, Eq. (6) becomes

$$S(t) = (Q_i - Q_s)u_r(t) + Q_s u_s(t) + Q'_s u'_s(t) - Q_i[f(t) + m(t) + c] - Z(t) \quad (11)$$

The rate structure applied by the utility to Clark may be made explicit by the relation

$$u_r(t) = p u_w(t) \quad (12)$$

where p is a multiplier and $u_w(t)$ is the utility's wholesale cost. At present p is about 1.2. The time dependence (escalation) of various quantities was expressed through exponentials:

$$f(t) = f(0)\exp\phi t \quad (13a)$$

$$m(t) = m(0)\exp\mu t \quad (13b)$$

$$u_w(t) = u_w(0)\exp\omega t \quad (13c)$$

$$u_s(t) = u_s(0)\exp\sigma t \quad (13d)$$

$$u'_s(t) = u'_s(0)\exp\sigma' t \quad (13e)$$

$$Z(t) = Z(0)\exp\zeta t \quad (13f)$$

In principle each of the rate constants ϕ , μ , ω , σ , σ' , and ζ can be different. For lack of distinct reasons to assume the contrary, we took as base case all rate constants equal to the general inflation rate, y . Under these conditions the model equation takes the form

$$S(t) = \{(Q_i - Q_s)u_w(0)p + Q_s u_s(0) + Q'_s u'_s(0) - Q_i[f(0) + m(0) + c \exp(-yt)] - Z(0)\} \exp yt \quad (14)$$

and the savings in constant dollars has the form

$$\tilde{S}(t) = \exp(-yt)S(t) \quad (15)$$

In this simplified form, our evaluation model for the savings therefore depends on 12 parameters as follows: Q_i , Q_s , Q'_s , $u_w(0)$, p , $u_s(0)$, $u'_s(0)$, $f(0)$, $m(0)$, c , y , and $Z(0)$.

In order to obtain an estimate of the quality of investment, we also considered the internal rate of return. For this we first obtained the net cash flow, defined by

$$NCF(t) = S(t) + C_i \quad (16)$$

and then applied the implicit definition of the internal rate of return

given by

$$\sum_{t=1}^{\text{system life}} \frac{\text{NCF}(t)}{(1 + \text{IRR})^t} = \text{Initial Capital Cost} \quad (17)$$

In evaluating systems we insisted that the internal rate of return be 10% or higher. As will be seen below, many systems failed to meet this simple criterion, and were therefore eliminated from consideration.

1.5.2 Base case assumptions

Certain parameters, such as the price of oil, recur in evaluation of all ICES. We therefore held these constant throughout our comparison of candidate systems, and summarize their assumed values in Table 1.5.2 below. In a later section, after our initial choice of system has been determined, we indicate the effect of varying these (and other) parameters in order to determine the sensitivity of system returns to such change.

Table 1.5.2-1 Base case assumptions

Variable	Variable name	Value
Rate of inflation	y	6%/yr
Price of fuel (current)	-	
#2 oil		\$3.00/MBtu
#6 oil		\$2.50/MBtu
Prices of electricity (current)		
Purchased by Clark	$u_r(0)$	4.2¢/kwh
Sold by Clark, Weekdays 7 A.M. - 11 P.M.	$u_s(0)$	2.4¢/kwh
Sold by Clark, other	$u'_s(0)$	2.0¢/kwh
Standby charge	$Z(0)$	\$25,000/yr
Rate structure factor	p	1.2
Plant lifetime	-	20 years
Clark electric demand	Q_t	6.6×10^6 kwh/yr
Conventional boiler efficiency	-	85%*

*This value used only in initial system comparisons. Clark boiler efficiency is actually 75%.

1.5.3 Initial comparison of 14 candidate ICES

We began our analysis by comparing 14 systems listed in Table 1.5.3-1. This list includes single and multiple diesels, gas turbines and steam turbines. For this initial comparison we used the base case parameters listed in the previous section, maintenance costs summarized in Table 1.5.3-2, and capital costs and other parameters as provided by the manufacturers. The candidate systems are described in detail in Appendix 1C. In each case, an annual rate of return was obtained, using the model described in Section 1.5.1.

Table 1.5.3-3 summarizes the principal features of the 14 systems. Examination of the table shows that only three systems meet our initial selection criterion of an internal rate of return greater than 10%. These are systems IV, IVB and IX. All are single diesels, ebulliently cooled. Systems IV and IVB are identical except for fuel: System IVB has a better rate of return because it is fueled by #6 oil. Systems IVB and IX are very similar except for size: System IVB has a better rate of return because it is smaller. We conclude that the best system appears to be a single, #6 oil-fueled diesel that is not too large--in the range of 1500 kW electrical output. We also conclude that steam turbines are, as our previous qualitative arguments indicated, out of the question.

1.5.4. Diesel size, fuel and loading.

To make explicit the importance of size and fuel for diesel systems, we have calculated the internal rate of return for several cases as a function of the price paid for excess electricity by the utility. Results appear in Fig. 1.5.4-1. From this we see:

- (1) The line for the 1500 kW that uses #6 oil lies 5 units higher in internal rate of return than the engine that uses #2 oil.
- (2) Larger engines indicate a rapidly falling internal rate of return with decreasing utility credit, even though they use #6 oil.

In addition we point out that some adjustment of the internal rate of return is possible if Clark takes care not to sell power to the utility at those times when this would involve a loss (e.g. at night or during weekends in the case of an engine that uses distillate oil). To illustrate, we have calculated in Fig. 1.5.4-2 modified curves (dashed lines) that apply to the case when sales are restricted to utility peak times, all for

Table 1.5.3-1 Candidate ICES - Initial List

<u>Case</u>	
I	Two 870 kw, 1200 BHP, 750 RPM, 8 cylinder diesels, G-M Model S-8E4G with waste heat boiler.
II	One 2210 kw, 3055 BHP, 20 cylinder diesel, 750 RPM, G-M Model S20E4G with waste heat boiler.
III	One 1780 kw, 2460 BHP, 16 cylinder diesel, 750 RPM, G-M Model S-16E4 with waste heat boiler.
IV	One 1530 kw, 2160 BHP, 720 RPM, 9 cylinder diesel, Colt Fairbanks-Morse Model 38TD8-1/8 with waste heat boiler.
V	Two 850 kw, 1200 BHP, 900 RPM, 6 cylinder diesels, Colt Fairbanks Morse Model 38D8-1/8 with waste heat boiler.
VI	Two 780 kw, 1100 BHP, 6 cylinder diesels, 750 RPM, Sulzer Model No. ASL25/30 with waste heat boiler.
VI-B	Three 700 kw, 16 cylinder diesels, 1200 RPM, Caterpillar Model 399 including a waste heat boiler for each unit.
VII	One Colt Pielstick 4550 kw, 6420 BHP, 514 RPM, 12 cylinder diesel, Colt Pielstick Model No. 12PC2V with waste heat boiler.
VIII	One DeLaval Enterprise 2591 kw, 3656 BHP, 450 RPM, 6 cylinder diesel. Enterprise Model No. R-46 with waste heat boiler.
IX	One Sulzer 3030 kw, 4200 BHP, 514 RPM, 6 cylinder diesel, Sulzer Model No. Z40 with waste heat boiler.
X	One noncondensing steam turbine, 904 kw, 600 psig, 700°F, 125 psig back pressure.
X-B	Same as X but 365 kw.
XI	One condensing extraction steam turbine plus boiler, 600 psig, 700°F, 125 psig extraction, various outputs.
XII	Two International Harvester 800 kw solar gas turbines.

Table 1.5.3-2 Maintenance Cost Estimates *

720 RPM Engines	#2 Oil	1530 kw Case IV	0.004 \$/kwh
450-514 RPM Engines	#6 Oil	4550 kw Case VII 3030 kw Case IX	0.004 \$/kwh
600-700 RPM Engines	#6 Oil	Case IV-B	0.005 \$/kwh
1200 RPM Engines	#2 Oil	700 kw Case VI-B	0.008 \$/kwh
Gas Turbine	#2 Oil	Case XII	0.006 \$/kwh
Steam Turbine		Case X & XI	0.015 \$/kwh

* These costs include normal maintenance and major overhaul. The figures were developed from:

1) discussions with the diesel engine, boiler and turbine manufacturers,

2) the MIUS Technology Evaluation for Prime Movers, April 1974, G. Samuels and J.T. Meador, Oak Ridge National Laboratory, Contract No. W-7405 eng.-26

3) ASME "1975 Report on Diesel and Gas Engine Power Costs"

4) the 1200 RPM diesel maintenance cost for the Caterpillar Diesel, Case VI-B figure was taken directly from the manufacturer and is based on his contract operating experience

5) our belief that higher speed units would require greater maintenance than lower speed units and that residual oil engines would require greater maintenance than distillate engines.

TABLE 1.5.3-3

ECONOMIC COMPARISON OF ENGINE ALTERNATIVES (LOCATED INSIDE JONAS CLARK)

Case No.	Description	Fuel Type	Total Capital Costs		Rated Electrical Load kW	kWh Generated by Clark	kWh Used by Clark	kWh Sold to NEES	Incremental Fuel Cost \$/kWh	Revenues		Fuel Cost \$	Costs Maintenance \$	Standing Charge (9 Months) \$	First Year Net Cash Flow \$	First Year Payback Years	Internal Rate of Return %	First Year Profitability \$/yr
			\$	\$/kW		10 ⁶ kWh	10 ⁶ kWh	10 ⁶ kWh		Power Used at Clark \$	Power Sold to NEES \$							
I.	2 GM Diesel** 870 kW	Distillate	1,108,000	640	1,740	12.63	6.47	6.45	0.02487	271,700	141,900	314,100	50,500	25,200	23,800	46.6	<4.0	-6,400
II.	1 GM Diesel** 2210 kW	Distillate	980,000	440	2,210	16.05	6.47	9.87	0.02384	271,700	217,100	382,600	64,200	25,200	16,800	58.3	<4.0	-16,200
III.	1 GM Diesel** 1780 kW	Distillate	882,000	495	1,780	12.92	6.47	6.74	0.02367	271,700	148,300	305,900	51,700	25,200	37,200	23.7	4.5	13,200
IV.	1 FM OP Diesel* 1531 kW	Distillate	820,000	535	1,531	11.17	6.47	4.94	0.02139	271,700	108,700	238,900	44,700	25,200	71,600	11.5	12.5	49,300
IVb.	1 Diesel 1531* kW	Residual	886,000	585	1,531	11.17	6.47	4.94	0.01649	271,700	108,700	184,200	55,900	25,200	115,100	7.7	18.0	91,000
V.	2 FM OP Diesel* 850 kW	Distillate	1,221,000	700	1,700	12.34	6.47	6.16	0.02318	271,700	135,500	286,000	61,700	25,200	34,300	35.0	<5.0	1,600
VI.	2 Sulzer Diesel** 780 kW	Distillate	1,149,000	740	1,560	11.33	6.47	5.15	0.024	271,700	113,300	271,900	45,300	25,200	42,600	27.0	<5.0	11,300
VIIb.	3 Caterpillar* 700 kW	Distillate	956,000	680	1,400	10.17	6.47	3.99	0.02161	271,700	87,800	219,800	81,400	25,200	33,100	28.9	<5.0	7,100
VII.	1 Colt Pielstick* 4550 kW	Residual	2,455,000	540	4,550	29.49	6.47	23.02	0.01689	271,700	506,400	498,000	118,000	25,200	136,900	18.0	7.0	70,000
VIII.	1 Enterprise** 2591 kW	Residual	1,892,000	730	2,591	18.81	6.47	12.63	0.01898	271,700	277,900	357,100	75,300	25,200	92,000	20.6	5.5	40,500
IX.	1 Sulzer* 3030 kW	Residual	1,932,000	640	3,030	22.96	6.47	16.49	0.01620	271,700	362,800	372,000	91,800	25,200	145,500	13.3	10.5	92,900
X.	1 Steam Turbine Noncondensing	Residual	978,400	3,100	365	1.87	1.87	0	0.0188	78,500	0	35,200	2,800	0	40,500	24.2	4.5	13,900
			1,139,000	1,260	504	1.43	1.43	0	0.01840	60,100	0	26,300	2,100	0	31,700	36	<4.0	700
XI.	1 Steam Turbine Extraction/Condensing	Residual	1,806,000	Not considered in detail. Economics worse than noncondensing steam turbine. See text for explanation.														
XII.	2 Solar Gas Turbines 800 kW	Distillate	922,000	580	1,600	11.87	6.47	5.4	0.0258	271,700	118,800	302,700	71,200	25,200	-8,600		0	0

* Ebulliently Cooled Diesel Engine (12 psig)

** Water Cooled Jacketed Diesel Engine (160 - 180°F)

Base Conditions: A. Value of Power Used by Clark - \$0.042/kWh
 B. Value of Power Sold - \$0.022/kWh
 C. Fuel, Power and Maintenance Escalated at 6%/yr
 D. Life of Equipment - 20 years
 E. Efficiency of Conventional Boiler - 85%

Maintenance Costs: Diesel 1200 RPM, No. 2 Oil - \$0.008/kWh
 900 RPM, No. 2 Oil - \$0.006/kWh
 720 RPM, No. 2 Oil - \$0.004/kWh
 720 RPM, No. 6 Oil - \$0.005/kWh
 450-514 RPM, No. 6 Oil - \$0.004/kWh
 Steam Turbine - \$0.0015/kWh
 Gas Turbine - \$0.006/kWh

Fig. 1.5.4-1: Internal rate of return as a function of engine size and fuel

Fig. 1.5.4-2: Effect of not selling to the utility when the price is less than the production cost.

the case of the 1530 kW engine.

1.5.5 Sensitivity Analysis

In order to see how much the economic benefits vary with changes in key parameters, we have conducted a sensitivity analysis in terms of savings, $S(t)$, defined in Section 1.5.1. Parameters varied are specified in Table 1.5.5-1. The base case for four engines (including one added since the original 14 system survey) is shown in Fig. 1.5.5-1. Sensitivity plots for the FM 1530 kW machine fueled by #6 oil are shown in Fig. 1.5.5-2.

Table 1.5.5-1
Key Parameters for Sensitivity Analysis

KEY PARAMETERS	BASE VALUES	VARIATION
Efficiency of Clark Boiler	.75	.85
Interest Rate on Loan	.03	.06
Retail Electricity Rate Multiplier	1.2	1.35 (flat rate is
Rate of Fuel Price Escalation	.06	0-.12 1.5)
Credit for Electric Capacity	0	.6¢/kwh
Underestimate of Capital Costs	0	\$200,000

Our conclusions are as follows.

(1) Changing the boiler efficiency from 75% to 85% (by purchasing economizers) reduces ICES savings by about 8%.

(2) Going from 3% to 6% interest in financing reduces ICES savings by about 30%.

(3) Increasing the rate structure multiplier from 1.2 to 1.35 nearly doubles the ICES savings.

(4) Varying oil price escalation from 0 to 12% has an effect on ICES savings that lies largely in the future; the former leads to slightly declining savings, the latter produces annual savings in the 10th year that are nearly double the base case.

(5) Giving a 0.6¢/kwh credit for capital in the case of electricity sold to the utility increases savings by over 50%.

(6) Assuming a \$200,000 capital cost overrun reduces annual savings by an average of 15%.

(7) Assuming the random occurrence of all of the above effects produces savings variations that range from 0.6 to 1.5 times the base case. Even the lower limit of this range has a minimum saving of \$40,000/year.

It is therefore clear that even quite large deviation from the base case produces no unacceptable loss in savings, and may provide in certain not implausible circumstances a substantial increase over the base case.

Fig. 1.5.5-1: Base case savings for four engines

Fig. 1.5.5-2: Sensitivity of savings for the Fairbanks Morse engine burning #6 oil. Base case is shown as solid line, variation by dotted line. The variation used is defined in Table 1.5.5-1

1.5.6 Energy Savings of ICES

We show the electric and thermal efficiencies of our candidate systems in Table 1.5.6-1. For comparison, we include gas turbines and steam turbines. We also show the amount of oil saved in the total demonstration system. The total demonstration system is compared to the conventional system which supplies Clark's electricity and heat, plus the electricity that Clark's exports would replace. Diesels would save 20-40% of the fuel presently used at Clark.

Table 1.5.6-1
ICES Efficiencies

ICES	Electric Efficiencies	Thermal Efficiencies	Energy Saved 10^9 Btu
Fairbanks-Morse	35%	33%	44
Superior	35%	35%	36
Sulzer	35%	35%	98
Gas Turbine (Solar)	21%	40%	38
Steam Turbine	$\leq 7\%$	$\leq 78\%$	9

In Fig. 1.5.6-1 we show these savings graphically. All of the diesels save large amounts of energy, and the steam turbine saves a negligible amount. The particularly poor savings of this steam turbine came about in part because its small size gives poor performance, but it is still quite generally true that for any ICES heat load, a steam turbine, because of its low electric efficiency, gives a much smaller total fuel savings than a diesel.

We show this contrast in another way in Table 1.5.6-2 which gives first and second law thermodynamic efficiencies for sample systems. First law efficiency is the ratio: total energy used/total energy input. Second law efficiency can be simply stated as the ratio: minimum energy needed to perform a task/energy used for that task. It is important to remember that second law efficiency only has meaning with reference to a definite task. For Table 1.5.6-2, we took the task to be electricity generation plus providing steam for the distribution system, not space heating of the buildings. Diesels again are better than steam turbines on second law grounds.

Fig. 1.5.6-1: Energy Savings

Table 1.5.6-2

FUEL SAVED AND RELATIVE FIRST AND SECOND LAW EFFICIENCIES OF CANDIDATE SYSTEM

Description	Mode of Operation	Jacket Cooling	Total Fuel Used by Demonstration System F_{ds}	Total Fuel Required by Conventional System F_{cs}	Fuel Saved $F_{cs} - F_{ds}$	Heat Value of Electricity and Steam Produced H_{Es}	FIRST LAW*			SECOND LAW**		
							Efficiency of Demonstration System η_{ds}	Efficiency of Conventional System η_{cs}	Increase in Efficiency $\eta_{ds} - \eta_{cs}$	Efficiency of Demonstration System ϵ_{ds}	Efficiency of Conventional System ϵ_{cs}	Increase in Efficiency $\epsilon_{cs} - \epsilon_{ds}$
10 ⁶ Btu/yr							Percent					
FM OP Diesel 1530 kW***	Full Load	Ebullient	201.5	241.8	40.3	146.8	72.8	60.7	12.1	40.3	33.6	6.7
	Part Load	Ebullient	174.0	199.4	25.4	132.6	76.2	66.5	9.7	37.6	32.8	4.8
Pielstick Diesel 4540 kW	Full Load	Water	145.4	428.7	283.3	209.3	60.6	48.8	11.8	43.6	35.2	8.4
	Full Load	Ebullient	327.1	428.7	101.6	209.3	64.0	48.8	15.2	46.1	35.2	10.9
Sulzer Diesel 1030 kW	Full Load	Water	298.1	362.1	64.0	187.1	62.8	51.7	11.1	42.5	34.9	7.5
	Full Load	Ebullient	276.7	362.1	85.4	187.1	67.6	51.7	15.9	45.7	34.9	10.8
Noncondensing Steam Turbine****	16,000 lb/hr	-	193.3	198.2	5.0	132.2	68.4	66.7	1.7	34.8	33.9	0.9
	32,000 lb/hr	-	194.2	198.2	4.0	132.2	68.1	66.7	1.4	34.6	33.9	0.7

* See text for definition of First Law Efficiency

** Second Law Efficiency defined as $\epsilon = \frac{\text{Thermodynamic Availability of Electricity and Steam}}{\text{Thermodynamic Availability of Fuel Input}}$

*** Hypothetical 1531 kW engine has same performance

**** Performance of extraction/condensing turbine would be worse than noncondensing turbine

comparison is to 85% boiler

1.5.7 Summary of energy and economic comparisons

We have shown that an ebulliently cooled single diesel with an electrical output of about 1500 kW and residual fuel capability is the system of choice. Such a system can be expected to have an internal rate of return of about 20%; it will save about 25% in fuel compared to a conventional system. Savings to Clark after financing costs are likely to be \$50,000 or higher in the first year. We have arrived at this conclusion after analyzing 14 candidate ICES systems, and making detailed cost and energy comparisons.

At present we are unable to identify an "off the shelf" diesel of the exact type we desire. Existing machines which come close to desired requirements are summarized in Table 1.5.7-1. All appear to be close to acceptable.

Table 1.5.7-1

Summary of the most favorable diesel ICES's

Manufac- turer	Elec- trical power ^a (MW)	fuel oil type	oil savings ^b (%)	Internal rate of return ^c (%/yr)	Capital cost ^d (\$1000)	Availability
Fairbanks Morse	1.5	#2	19	18	800	Production model
	1.3	#6	22	25	850	not confirmed
Superior	1.0	#6	17	20	950	Modified pro- duction model, confirmed Appendix 1D
Sulzer	3.0	#6	50	15	1,950	Modified pro- duction model, confirmed Appendix 1D

- a. Stated power level is maximum steady power level that can be produced by a given engine. Most engines can be run at about half of the stated level without serious loss of efficiency.
- b. Oil savings represent oil not needed at Clark or at the utility oil-fired power plants as a result of the proposed ICES. Percent savings are based on Clark's anticipated annual use of 30,000 bbls/yr.
- c. Internal rate of return gives payback realized before financing charges. It is based on the assumption that oil prices and all other prices escalate at 6% per year.
- d. Capital costs include engine price, engineering design, installation, and interconnect costs for heat recovery; they do not include costs of the grid connection. A new building would cost about \$180,000 more.

2. PRELIMINARY INSTITUTIONAL ASSESSMENT

We have examined five areas important to Clark's relationship with the outside community. These are: 1) statutes and codes; 2) community relations; 3) information dissemination; 4) legal problems, and 5) restrictions posed by the University charter. In general, the Worcester community and state and local officials have been gratifyingly receptive to Clark's plans for an ICES and most helpful in overcoming the various problems encountered.

2.1 Statutes and Codes

Four areas of regulation have major relevance to the Clark University ICES system. These are: (a) reciprocal zoning regulations; (b) municipal and state building and equipment codes; (c) state and federal air pollution regulations; and (d) state and federal environmental regulations. (This section will deal with each of these four areas individually.) More details are given in Appendix 2A, Environmental Evaluation Report. Complete codes and regulations are in a separate volume, Appendix 2B.

2.1.1 City of Worcester Zoning Ordinance

The City of Worcester Zoning Ordinance defines the permissible uses in a residential district. The use of the Clark ICES installation was discussed with Mr. Norton S. Remmer, Commissioner, City of Worcester, Department of Code Inspection. The Commissioner stated in his letter (Appendix 2C) that the proposed project would not violate existing zoning.

2.1.2 State Building Code

The applicable section of the State Building Code is Article 11, "Heating Equipment and Appliance Mounting, Clearances and Connections." In addition, boilers and unfixed pressure vessels are subject to the provisions of Chapter 146 of the Massachusetts General Laws as amended. In his letter, Commissioner Remmer states that compliance with all requirements of the building code can be achieved by application of

standard design and construction techniques. The provisions of Chapter 146 require approval of certain boilers and pressure vessels by the Board of Boiler Rules of the State Department of Public Safety. Such approval is usually routine. It can be obtained only after detailed designs and specifications are submitted.

2.1.3 Air Pollution Regulations

Federal and state air pollution regulations are practically identical. Major applicable regulations are: (1) Federal and Massachusetts Air Quality Standards (40 CFR 50); (2) Requirements for Preparation, Adoption and Submittal of Implementation Plans (40 CFR 51); (3) Interpretative Ruling for Implementation of the Requirements of 40 CFR 51.18; and (4) Regulations as Amended for the Control of Air Pollution, Department of Environmental Quality Engineering, The Commonwealth of Massachusetts, adopted January 26, 1972 and amended August 8, 1972, May 22, 1973, Oct. 29, 1974, May 13, 1975, and June 13, 1975. The Department of Environmental Quality Engineering is responsible for the control of air pollution in Massachusetts effective July 1, 1975, in accordance with provisions of Chapter 21A, Massachusetts General Laws as established by Chapter 806 of the Acts of 1974 as amended by Chapter 706 of the Acts of 1975.

Discussions with personnel concerned with air quality in EPA Region I (Boston) confirmed that existing state requirements would satisfy federal requirements. There are no EPA standards for diesel engine emission. Issue of such standards is expected in February, 1978 and there are indications that these standards will be met by most existing diesel engines. Massachusetts standards for fossil-fuel-utilizing facilities with a fuel input of less than 250×10^6 Btu/hr can be met by the most likely unit, the F.M. Colt 1530 kW diesel, with ease, and other possible units will also meet these standards. Following our presentation of the material relating to air pollution to Mr. Edward G. Benoit, Chief, Air Quality Control Section, Central Massachusetts Air Pollution Control District, Mr. Benoit stated in a letter (Appendix 2C) that in the opinion of his office, and based on presently available data, the project would not be in violation of existing air pollution regulations and standards.

2.1.4 Environmental Impact

Regulations regarding overall environmental impact analyses are contained in Chapter III, U.S. Energy Research and Development Administration Guidelines for Environmental Review and Rules and Regulations filed by the Executive Office of Environmental Affairs--Preparation of Environmental Impact Reports, filed Dec. 13, 1976 and published Dec. 23, 1976. The referenced ERDA regulations define an Environmental Impact Assessment as a written document which evaluates the environmental impacts of an ERDA action to assure the consideration of environmental values early in the decision making process. Part 711.25 of this regulation prescribes the content of an EIA.

The Environmental Evaluation Report (Appendix 2A) provides a preliminary environmental impact assessment of the Clark ICES plant based on our present state of knowledge of its most likely configuration. The overall conclusion is that environmental impacts are insignificant except as follows: (1) Compared to the present system there would be an approximate doubling in NO_x emission; (2) Compared to the present system, there would be a 20-25% reduction in oil use. At this stage of evaluation, the increase in NO_x emission is not a serious problem, because NO_x is a critical pollutant only as a contributor to photochemical smog, and this occurs only rarely in Worcester. In contrast, the decrease in oil consumption is viewed as being of major importance, especially if the ICES concept is extended to other sites.

2.2 Community Relations

Clark University is located in an older residential neighborhood about 1.2 miles south of the city center. While the relations of the University with its surrounding neighborhood are generally good, some conflicts exist, stemming from student parking, student competition for housing, and University expansion. New parking recently constructed and more under construction, as well as the announcement by the University that no further expansion is contemplated, have significantly mitigated these conflicts. There is no neighborhood association that speaks for the community. The Worcester Redevelopment Authority, an

agency that operates in the vicinity of Clark University, was contacted. It stated that it could not foresee any objections to an ICES at Clark. A letter to that effect is presented in Appendix 2C.

Relations of the University with the City of Worcester as a whole are very good. The University contributes significantly to the city through economic value of students and staff and direct assistance by faculty and student interns to city functions. Informal discussions with city staffs have uniformly produced positive reactions towards the implementation of an ICES at Clark.

2.3 Information Dissemination

Because Clark is an academic institution with a substantial record in the study of technology and environmental impact assessment, we are in a unique position to provide a comprehensive information program for the proposed Demonstration ICES. Written material will be prepared by the Program on Science, Technology and Society; site visits will be organized through the Office of the Physical Plant and the Office of Public Relations. Specifically, we envision six activities to inform the public and technical audiences about the project.

(1) Occasional press releases. Addressed to the general public, largely in the local community, these will indicate progress on the project, describe the general implications of cogeneration for the nation, and indicate the local impacts. In the post-construction stages, these releases will be used to invite the general public to visit the site and learn about its functioning. (See below.)

(2) Site visits. Provided for the general education of the public in the local area, these visits will allow touring of the facility. To make them meaningful, we will provide museum-like posters indicating principal functions and benefits, and we will arrange for student guides as needed.

(3) Performance data sheets. We will make available brief technical reports on operations performance characteristics of the Clark ICES as the project progresses. These will be addressed to technical audiences with an interest in cogeneration. We will distribute these data through NTIS if ERDA desires and will offer them through the Clark Program on

Science, Technology and Society in any event.

(4) Planning Workbook. For potential planners of other ICES we shall prepare a workbook that details the planning experience at Clark. It is our hope that, by describing our experience, our evaluation models, and the institutional problems we have faced and solved, we will help to initiate projects with considerably reduced effort. The workbook will be based on the major tasks of Phases I - III, and it is expected that a draft of it will be available at the end of Phase IV. As operating experience accumulates in later phases, it is expected that modifications will be made. The workbook will be distributed through NTIS if ERDA desires, and through the Clark Program on Science, Technology and Society in any event.

(5) Publication in journals and presentation at conferences. For the general public and for a broad technical audience it is of interest to consider cogeneration in a regional and national context. We have carried on general studies in this area for some years; we expect to continue this activity as the Clark Demonstration ICES matures, using information from it as additional input. We shall attend conferences and publish in technical and semi-technical journals (Environment, Technology Review, Bulletin of the Atomic Scientists, etc.), describing how cogeneration is evaluated in regional and national terms, and how the Clark demonstration and other related projects illustrate this evaluation. Based on Phase I work we have already submitted two papers to be read and published in conference proceedings as follows (abstracts are in Appendix 2D):

- (a) R. Collins, R. Goble and A.M. Gottlieb, "Energy Profiles at Clark University: Implications for Cogeneration," National Conference on Technology for Energy Conservation, Washington, D.C., June 1977;
- (b) R. Goble and S. Nydick, "Grid-connected cogeneration at Clark University: the effect of terms of utility interconnection," International Conference on Energy Management, Tucson, Arizona, October 1977.

(6) Consultation with the Massachusetts State Energy Policy Office. Because of our continuing connection with the State Energy Policy Office we expect that information generated at Clark will have significant impact on the State's efforts in the cogeneration area. Thus we expect to be called on to give testimony on our planning process, on the insti-

tutional problems we have faced and solved, and on the performance of our system. We will work closely with the newly formed Massachusetts Commission Studying Cogeneration.

2.4 Legal Problems

A preliminary analysis of legal problems relating to the proposed ICES at Clark University has been provided by Richard Mirick, Counsellor at Law and legal counsel to the University. A letter from Mr. Mirick appears in Appendix 2C. Based on this and our own assessment, we have identified two legal problems. With their actual and/or potential solutions, they are as follows.

2.4.1 State Department of Public Utilities

The manufacture and sale of electricity by Clark places the University under the jurisdiction of the State Department of Public Utilities (DPU) and requires conformance with applicable statutes and rules of that department. Appropriate discussions with NEES and the DPU on the implications of these rules are in progress. We have assurances that there will be no significant restrictions.

2.4.2 Worcester Local Zoning Ordinance

According to Mirick, the manufacture and sale of electricity by Clark could in principle be in violation of the City of Worcester Zoning Ordinance. In fact, there is no problem. As already indicated in Section 2.1.1, and by a supporting letter from Mr. Remmer (Appendix 2C), the project would not be in violation of zoning, and could proceed routinely for approval.

2.5 The University Charter

A preliminary analysis of problems relating to the University Charter has been given by Richard Mirick, legal counsel for the University. (See Appendix 2C.) With their actual and/or potential resolutions, these problems are as follows.

2.5.1 University Ownership of the Plant

Mirick states: "Although the University has no express power to engage in the generation of electric power, I am satisfied that it has the implied power to do so for its own internal use." We therefore do not anticipate any problems with the ownership of the plant per se and conclude that such problems as there are arise from the sale of electricity, as discussed below.

2.5.2 Corporate Power to Sell Electricity

In Mirick's opinion, it is possible that the University does not have the power to sell electricity. However, Mirick believes that this is not an actual problem; he states: "In view of the facts that the principal purpose of the proposed facility is to provide the University with its own energy needs, that any sales of excess energy would be incidental and in lieu of wasting such excess, and that the public has a direct interest in conserving energy, I conclude that this possibility is a theoretical rather than a practical cause for concern. If necessary, the University could seek a ruling from the Attorney General, or legislative approval, or separately incorporate a subsidiary to operate the facility."

2.5.3 Federal Tax-Exempt Status

In Mirick's opinion, the sale of electricity by Clark could be construed as unrelated business income and subject to federal taxation. A ruling from the Internal Revenue Service could be requested if ERDA desires. Such a ruling would be more meaningful near the end of Phase II, when preliminary design is completed. In the meantime we do not consider taxation for sold electricity as a problem, since the system is not likely to show any taxable profit.

2.5.4 Local Tax-Exempt Status

In Mirick's opinion, the sale of electricity by Clark may lead to consideration of real estate and equipment as subject to local real estate and property tax. It is our plan to seek remedy via state legisla-

tion that specifically exempts the ICES from such taxation. We do not believe it advisable, however, to engage in such action until the issue of taxation is raised by local authorities.

3. CONCEPTUAL DESIGN

The purposes of the conceptual design presented here are: (1) to identify the major components of the selected system; (2) to serve as a basis for preliminary cost estimates; and (3) to show that the components can be fitted into the site available.

3.0 System and Plant Description

In Section 1.5 we gave the reasons for our selection of the Fairbanks Morse 9 cylinder Model 38TD diesel producing 2160 bhp at 720 rpm with a 3 phase generator with a nameplate rating of 1531 kilowatts. Fig. 3.0-1 identifies the major components of the system. It should be noted that the fuel oil storage tanks shown are those already in existence at Clark, and that the centrifuge in the fuel line is only needed should #6 oil be used.

Major components and auxiliary equipment will be installed adjacent to the existing boiler room in one of two locations: (1) the biology laboratories in the basement of Jonas Clark Hall; or (2) in a new building to be erected adjacent to Jonas Clark Hall.

To illustrate, we show in Fig. 3.0-2 and 3.0-3 a possible plant layout in the first of the above sites. Though the exact location of all components is not shown, the sketch demonstrates that there is ample space for the equipment within the building. The space required for layout is 65' x 40'; the required headroom is 12'5". In order to remove inside load-bearing walls, it is necessary to take up building loads with steel beams. The waste heat boiler will be oriented in the building before the diesel generator is skidded into position. The diesel generator will be skidded into the building through a permanent access door. The unit will require inlet and exhaust silencers as shown and, for the alignment shown, will require a new stack.

The layout for a plant adjacent to Jonas Clark Hall is shown in Fig. 3.0-4. The choice between these two configurations will be made in Phase II, based on economic, aesthetic and risk considerations.

Fig. 3.0-1
SYSTEM SCHEMATIC

Fig. 3.0-2
CENTRAL PLANT LAYOUT INSIDE

COGENERATION SYSTEM LOCATED
IN JONAS CLARK HALL
SCALE: 1/4" = 1'-0"

Fig. 3.0-3

COGENERATION SYSTEM LOCATED
IN NEW BUILDING
 SCALE: $\frac{1}{4}'' = 1'-0''$

Fig. 3.0-4

3.1 Process Diagrams

We have made process diagrams for five subsystems, air cooling, air supply, fuel supply, lubrication and steam. The components of the first four are an integral part of the diesel engine and will be supplied by the engine manufacturer.

The Air Cooler System is shown in Fig. 3.1-1. It dissipates 400 Btu/bhp/hr. The heat is removed from the compressed intake air following the supercharger and is taken through a closed water loop to a heat exchanger, and from there via water to a cooling tower or alternative sink.

The Air System is shown in Fig. 3.1-2. Compressed air for starting and instrument control will normally be supplied by a motor-driven air compressor. A standby gasoline engine will be provided in the event of failure of the electric motor. Starting air pressure is 250 psig. Instrument air will be reduced from this pressure to pressures of 50 and 20 psig. Sufficient storage capacity will be provided to permit three successive starts. The air compressor will be sized to restore air to the reservoirs in one hour.

The Fuel Oil System is shown in Fig. 3.1-3. Fuel oil will be pumped from the existing 20,000 gallon storage facilities to a 2,000 gallon day tank which stores sufficient fuel for 24 hours of diesel operation at 1500 kW. The fuel oil filters are supplied as duplex units permitting cleaning and replacement of one side while the other side is in service.

The Lubricating Oil system is shown in Fig. 3.1-4. The pre-lube pump and electric heater are needed for starting. The oil is heated and circulated over the frictional parts prior to starting. The engine-driven lube oil pump takes over these services during engine operation. The lube oil cooler dissipates 775 Btu/BHP/hr to the surrounding air.

The steam, feedwater and condensate circuits are shown in Fig. 3.1-5. The deaerator (water softener) and condensate return tank, condensate return pump, and feedpumps are existing equipment in the present boiler plant. The waste heat boiler has evaporation and economizer sections, both consisting of spirally wound, finned tubes. The boiler will deliver saturated steam. The diesel engine jackets will be ebulliently cooled using an ebullient boiler. The system consists essentially of an elevated steam and water drum reservoir. The water head will keep sufficient pressure on the

Fig. 3.1-1. AIR COOLER SYSTEM

Fig. 3.1-2. AIR SYSTEM

Fig. 3.1-3. FUEL OIL SYSTEM

Fig. 3.1-4. LUBRICATING OIL SYSTEM

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Fig. 3.1-5. STEAM SYSTEM

jacket water to prevent boiling in the jacket. To control the pressure, ebullient condensers will be provided, and with pressure control the steam from the jacket system will be condensed and returned to the condensate return tank. A cooling tower will provide cooling water for the ebullient boiler condensers when the heating load is not sufficient.

Figure 3.1-6 shows the connection of the ICES to utility lines and to the Clark electricity distribution system shown in Figure 1.1-2. Detailed requirements for the connection are given in Appendix 3A.

3.2 Cost and Performance Estimates

Cost estimates for the Fairbanks Morse 1531 kW diesel system are presented in Table 3.2-1, with separate results for each of the two sites. The construction of a new building adds about \$186,000 to the project cost. A new building may nevertheless be desirable, both for reducing the risk involved in modifying an existing building, and for aesthetic reasons.

Performance data for the Fairbanks Morse 1531 kW diesel system are presented in Table 3.2-2. Nearly all of these are explicitly provided by the manufacturer.

Cost and performance data for other engines appear in Appendix 1C.

Note 1. This shows the existing 3-wire, 13.8 kV metering arrangement. A third meter would be required for conventional IN-OUT metering of kWh. Two more meters would be required for IN-OUT metering of kVARh.

ONE LINE DIAGRAM FOR GRID CONNECTION

Fig. 3.1-6

Table 3.2-1. Cost Analysis for the FM 1531 KW Diesel System

Item	Cost (units of \$1,000)	
	Jonas Clark	New building
<u>Equipment</u>		
Engine, generator and switchgear	369	369
Boiler	32	32
Ebullient boiler	9	9
Cooling tower	2	2
Crane	10	10
Water softener	6	6
Freight	21	21
<u>Civil work</u>		
New building		228
Miscellaneous alterations	47	
Engine foundation	14	14
Boiler foundation	3	3
Acoustical	18	
Fire proofing	5	
Remove #1 boiler	5	
<u>Mechanical and electrical work</u>		
Rig engine	9	9
Rig in boiler	4	4
Align engine	2	2
Install ducts	13	13
Piping, hangers, valves	31	31
Heating alterations	37	37
Electrical work	15	15
Instrumentation	8	8
Ventilation	12	12
<u>Engineering cost</u>	148	181
<u>Total Project Cost</u>		
Equipment	449	449
Civil Work	92	245
Mechanical and electrical work	131	131
Engineering cost	148	181
PROJECT TOTAL	820	1006

Table 3.2-2. Performance Data for FM 1531 KW Diesel System

Fuel oil	#2	
Electrical output (maximum)	1531 KW	
Steam generation		
low pressure	979 lbs/hr	
high pressure	2983 lbs/hr	
Incremental heat use	6596 But/kwh	
Fuel cost	2.1¢/kwh	
Electric-steam ratio		
generated	0.38 kwh/lb.,	0.33 kwh/1000 Btu
used	0.38 kwh/lb.,	0.33 kwh/1000 Btu
Heat balance		
fuel	6555 Btu/bhp	
power	2545 Btu/bhp	
jacket	465 Btu/bhp	
exhaust	2230 Btu/bhp	
lube oil	775 Btu/bhp	
air cooler	400 Btu/bhp	
radiation	140 Btu/bhp	
Exhaust specifications		
NO _x	9 gm/bhp/hr	
CO	1 gm/bhp/hr	
HC	0.4 gm/bhp/hr	
particulates	0.125 gm/bhp/hr	
SO ₂	1.66 gm/bhp/hr	

4. FIRMING OF COMMITMENTS

4.0 Firming of Commitments

We have made the commitments necessary for continuation of the demonstration program. These commitments are as firm as is feasible or desirable at our present stage of planning. We have preliminary contractual agreements for design and construction of the ICES, and we have made a mutually acceptable preliminary agreement with the New England Electric System on terms of interconnection. Letters confirming these agreements are shown in Appendix 4A.

There are two areas in which "as firm as feasible" is still not very firm. One is financing. It is now clear to us that the best mode of financing would be a federally subsidized loan for energy conservation. However, such loans are only now becoming available, and it is still uncertain just what will be available and what regulations will apply. Hence it is too early for us to settle a detailed financing arrangement. The second is the acquisition of permits. While we have been assured that, given our present plans, there will be no problems in obtaining permits, actual permits can only be given based on final design.

4.1 Financing

For Phase I we have investigated four alternative methods of financing the ICES demonstration: 1) borrowing from the endowment, (2) a commercial loan, (3) a Health and Education Facilities Authority (HEFA) bond issue, and (4) long-term borrowing under one or more federal loan programs. We anticipate a total system cost of approximately one million dollars. This is a substantial investment for Clark University. Because it will be at rates of return permitting full pay-back only after a number of years, the short-term financing options (1) and (2) would be unacceptable as the major source of funds. Furthermore, we have ascertained that there are insufficient unrestricted endowment funds to permit use of option (1). HEFA bond issues or federal loans would permit long-term financing. We have explored the possibility of an HEFA bond issue for financing the ICES while making arrangements for issuing bonds to finance our new gymnasium. We have uncovered a number of difficulties with an HEFA bond issue. The most serious of these is

that it will be necessary to secure the loan, and the plant itself would not be adequate security. There may not be sufficient unrestricted endowment funds for this purpose or, even if there are, their use could seriously limit Clark's borrowing capability.

Though we are not ruling out an HEFA bond issue at this time, we would strongly prefer to secure our major financing through a federally subsidized loan for purposes of energy conservation. We are making applications to two programs. One, to be administered by Housing and Urban Development (HUD), will provide bonds at 3% for energy conservation in dormitories and dining areas. The second is authorized by the Higher Education Facilities Act. It will provide for loans and some matching grants for investments in academic buildings for the purpose of saving energy. Further financing possibilities exist in other bills presently before Congress and in President Carter's energy program. We expect that all of these possibilities will be sufficiently clarified so that we can decide on the mode of financing by the end of Phase II.

4.2 Fuel Availability

If oil and gas became unavailable sometime during the ICES lifetime, we and the rest of Massachusetts would have worse problems than those caused by not operating the ICES. If there should be a shortage of these fuels we would expect to have a fairly high priority in allocation; this is because we are a residential community and because the ICES would be energy-efficient. We do not use sufficient fuel to be subject to a specific allocation. Instead, our suppliers will be allocated oil in amount depending on the nature of their customers.

4.3 Ownership

Clark University will own and operate the demonstration ICES. We have made tentative agreements with Thermo Electron Corporation for design and construction of the ICES, with Fitzmeyer and Tocci for modification to the existing heating system, and with the New England Electric System for design of the grid interconnection. Letters spelling out these agreements are in Appendix 4A.

4.4 Terms of Grid-Connection

We have made a preliminary agreement with NEES for interchange. The agreement is mutually acceptable as a basis for final negotiation (see the letters from John Stevens, NEES, and Frank Puffer, Clark, Appendix 4A). Under the agreement there would be no restrictions on interchange. Clark purchases will be made only for demand in excess of what the ICES provides at any given time. Clark would buy electricity at published rates. These rates include a standby provision under which Clark must agree to pay at least a certain minimum which depends on the peak demand Clark might put on the system. At present, all purchases would be at one of the standard rates, provided the minimum charge is passed. However, NEES has notified us that they expect to request the Department of Public Utilities for permission to have a standby charge independent of purchases. Clark will respond to this proposal when we learn the proposed terms.

Clark will sell the excess electricity when local demand is smaller than the ICES output. NEES will purchase this excess at a price closely approximating the cost of the oil Clark's export displaces. The price will be calculated by multiplying the New England Power average fuel price (including hydro and nuclear) by a factor which depends on time of day and which is designed to convert average fuel price to the displaced oil cost. There will be two multipliers, one for weekdays, 7 A.M. to 11 P.M., the other for the remaining times. The multipliers will be recalculated periodically to take into account changes in the relation between average and displaced fuel cost; the average fuel cost is recalculated every month. Recalculation of the multiplier is necessary when there are major changes in the price of oil. For example, the multipliers quoted by Mr. Stevens in the letter shown in Appendix 4A were based on 1976 data. Since then the oil price NEES pays has increased by 30% while the average fuel cost has only increased 23%; consequently, the quoted multipliers must be too small by about 7%. The displaced oil cost now averages approximately 2.2¢/Kwh, at today's oil prices.

The present auxiliary power schedule is shown in Appendix 4B.

5. DETAILED WORK MANAGEMENT PLAN

5.1 Task Definitions and Schedules

In this section we describe the work management plan required for completion of the ICES demonstration program at Clark University. The plan is divided into Phases II-VI. Phase I, just completed, concludes that the optimum ICES would be an ebulliently cooled diesel with electrical output of 1-3 MW, with average load factor of 85%, and with approximately 25-70% of the generated electricity fed to the utility grid.

Phase II focuses on the final selection of the engine and its fuel, completion of the institutional assessment, preliminary design, and a final decision by the Clark Trustees to implement or not to implement construction of the plant.

Phase III is concerned with final design of the demonstration system, specification of operation and maintenance procedures; completion of the negotiations with NEES, completion of the financing and legal requirements, and revision of the energy-economic analysis, if necessary.

Phase IV is concerned with construction and installation of the demonstration system, including management, procurement and reporting thereon.

Phase V involves starting and testing the demonstration system.

Phase VI involves long-term evaluation of the system, largely in terms of energy-economic characteristics.

The essential tasks for each phase, with our proposed schedule for them, are shown in Figures 5.1-1 to 5.1-5.

5.2 Organizational Chart and Identification of Key Personnel

At this time we intend to go ahead with the team identified in the original proposal, organized in the same manner as previously given, with the following additions and deletions.

(1) The Massachusetts State Energy Policy Office will not participate formally because they are not permitted to receive contract support.

(2) For Phase II, Clark will require architectural consultants (Task

TASK DESCRIPTION

Task 1: Complete Energy-Economic Analysis

- A. Fuel price projection and availability
- B. Update energy profiles
- C. Survey available diesels
- D. Update installation and interconnect cost
- E. Final economic comparisons of diesel systems
- F. Final choice of diesel system
- G. Update system economics

Task 2: Complete Institutional Assessment

- A. Full analysis of codes and regulations
- B. Final environmental impact assessment
- C. Full analysis of legal problems
- D. Determine additional details on finance

Task 3: Preliminary Building Design

- A. Layout of system in Jonas Clark Hall
- B. Layout of system in separate building
- C. Final choice of building design

Task 4: Engine System Preliminary Design

- A. Design grid interconnection
- B. Preliminary design analysis
- C. Perform system layout
- D. Schematic block diagrams of subsystems
- E. Material and process specifications
- F. Applicable material specifications
- G. Detailed procurement schedules
- H. Component test requirements
- I. Mockups

Task 5: Firming up Commitments

- A. Update interconnect agreement
- B. Update legal responsibilities of Clark
- C. Update approval on codes and regulations

Task 6: Detailed Work Plan

- A. Update detailed work plan
- B. Cost estimates for work in subsequent phases

Task 7: Decision to Implement

- A. Report to Clark Trustees on Tasks I-VI
B. Decision of Trustees on implementation

Task 8: Report to ERDA on Phase II

- A. Summary of Tasks 1-7
- B. Application of support for subsequent phases,

FINAL ENGINE CHOICE

COMPLETE PRELIMINARY DESIGN

CLARK TRUSTEE DECISION

REPORT ON PHASE II TO ERDA

Fig. 5.1-2

PHASE III: FINAL DESIGN AND RELATED ACTIVITIES

TASK DESCRIPTION

PAID BY CLARK UNIVERSITY

Task 1: Engine System Design

- A. Design analysis, engine plant
- B. Flow diagram
- C. Detailed engine system layout and construction working drawings
- D. Detailed distribution system, building design and work drawings
- E. Mockup and models
- F. Procurement specifications
- G. Construction specifications
- H. Construction cost budget

PAID BY ERDA

Task 2: Design of Monitoring System

- A. Design analysis, monitoring system
- B. Monitoring system layout and working drawing
- C. Procurement specifications
- D. Installation specifications
- E. Cost budget

Task 3: Operations and Maintenance Procedures

- A. Specifications of procedures
- B. Operations and maintenance manual

Task 4: Institutional Commitments

- A. Final resolution of legal issues relating to the Clark University Charter
- B. Final resolution of issues relating to code compliance, environmental impact
- C. Final resolution of financing issues

Task 5: Grid Connection

- A. Final resolution of legal issues relating to the grid connection
- B. Final agreement on grid connection
- C. Design of grid connection

Task 6: Design of energy conserving equipment required by ERDA, if any

Task 7: Detailed Work Plan

- A. Detailed work plan for subsequent phases
- B. Update cost estimates for subsequent phases

Task 8: Demonstration Information Program

- A. Prepare technical reports detailing regional and national implications of Phases I and II
- B. Prepare draft planning workbook on the Clark planning experience

Task 9: Report to ERDA on Phase III

- A. Summary of tasks 1-8
- B. Application of support for subsequent phases

Fig. 5.1-3

PHASE IV: CONSTRUCTION

TASK DESCRIPTION	MONTHS																				
	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
<u>PAID BY CLARK UNIVERSITY</u>																					
Task 1: Construction Management Plan																					
Task 2: Engine System Construction																					
A. Building modification and site preparation																					
B. Equipment purchase and procurement																					
C. Component fabrication																					
D. Install engine system																					
<u>PAID BY ERDA</u>																					
Task 3: Monitoring System Installation																					
A. Equipment purchase and procurement																					
B. Equipment installation																					
Task 4: Grid Connection Installation																					
A. Equipment purchase procurement																					
B. Component fabrication																					
C. Equipment installation																					
Task 5: Construction Reports																					
A. Records and reports of deliveries																					
B. Records of installation and construction systems																					
C. Changes in drawings																					
D. Daily construction log and photos																					
Task 6: Demonstration Information Program																					
A. Prepare press release informing local community of construction and implications																					
B. Prepare technical report on regional and national implications of final design adopted.																					
C. Final draft, planning workbook																					
Task 7: Detailed Work Plan																					
A. Detailed work plan, subsequent phases																					
B. Update cost estimates for subsequent phases																					
Task 8: Report to ERDA on Phase IV																					
A. Summary of tasks 1-7																					
B. Application for support in subsequent phases																					

Fig. 5.1-4

PHASE V: STARTUP AND PERFORMANCE TESTS

TASK DESCRIPTION	MONTHS																	
	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
<u>TO BE PAID BY ERDA</u>																		
Task 1: Demonstration System Installation Test																		
A. Engine system installation test																		
B. Monitoring system installation test																		
C. Report to ERDA on installation tests																		
Task 2: Startup Tests																		
A. Engine system startup tests																		
B. Monitoring system startup test																		
C. Report to ERDA on startup tests																		
Task 3: Performance Tests																		
A. Engine system performance test																		
B. Monitoring system performance test																		
C. Report to ERDA on performance tests																		
Task 4: Demonstration Information Program																		
A. Provide display facilities for demonstration system site visits by general public																		
B. Issue press release informing local community of system startup, availability of site visits																		
C. Publish technical report on monitoring and performance test, indicate implications of this on a regional and national basis. State results in terms of energy-economic models																		

TASK DESCRIPTION

YEARS

Task 1: Engine System Operation and Maintenance.

Task 2: Monitoring system operation and maintenance.

Task 3: Periodic reports to ERDA on engine system operation and maintenance.

Task 4: Periodic reports to ERDA on monitoring system results.

Task 5: Evaluation of Engine System operation and monitoring, report of same to ERDA.

Task 6: Demonstration Information Program

A. Issue periodic press releases to inform local community of demonstration system evaluation.

B. Prepare technical publications for journals and conferences, indicating regional and local impact of system evaluation, state results in terms of energy-economic models.

C. Update planning workbook.

D. Continue site visit program as needed.

[illegible]

II-3), the identity of whom is not currently specified.

A sketch of the planned organizational structure appears in Fig. 5.2-1. For qualifications of personnel, refer to the original proposal. It is likely that, as the project proceeds to final design, an executive director will have to be added directly below the Program Administrator.

5.3 Manpower Requirements

Based on the phase schedules shown in Section 5.2, we have prepared preliminary manpower estimates as described in Tables 5.3-1 through 5.3-5. A detailed manpower estimate for Phase II is shown in Table 5.3-6.

5.4 Project Costs

From the manpower and equipment estimates we have made projections for the total cost of the project. These projections are shown in Table 5.4-1. The costs shown include equipment, construction and engineering costs, certain first-of-a-kind engineering and institutional costs as well as costs directly attributable to the demonstration process per se. They are therefore greater than the costs to Clark shown in Table 3.2-1.

5.5 Replication Costs

We have asked: "What would be the cost, given that a Clark demonstration program exists, for a similar institution to design and install a similar power plant?" The question can not be answered by simply using the task definitions of the demonstration program phase schedules. The reason is that these tasks and phase schedules are explicitly designed to permit maximum control and intervention by ERDA in the direction of the demonstration program, and for this reason they include many activities that would not be engaged in by a replicating institution, including some outright repetition of activities. We have therefore made a new task description with corresponding man-hours which shows that for the FM 1531 KW diesel replication costs would be \$934,000. This analysis is shown in Table 5.5-1. Similar analysis was also performed for the other three candidate systems included in our summary table, 1.5.7-1. Results, with corresponding rates of return, are given in a revised summary table which appears as Table 5.5-2.

Fig. 5.2-1 Organizational Chart

PHASE II: DETAILED FEASIBILITY AND PRELIMINARY DESIGN

TASK DESCRIPTION	MAN MONTHS			
	CLARK	TECO	FITZ	NEES
Task 1: Complete Energy-Economic Analysis				
A. Fuel price projection and availability	0.5	0.1		0.1
B. Update energy profiles	1.5		0.1	
C. Survey available diesels		1.5		
D. Update installation and interconnect cost		0.5	0.5	0.1
E. Final economic comparisons of diesel systems		0.5		
F. Final choice of diesel system	0.1	0.1		
G. Update system economics	0.5	0.3		
Task 2: Complete Institutional Assessment				
A. Full analysis of codes and regulations	0.5		0.1	
B. Final environmental impact assessment	0.5		0.1	
C. Full analysis of legal problems	1.5			
D. Determine additional details on finance	0.5			
Task 3: Preliminary Building Design				
A. Layout of system in Jonas Clark Hall		0.5	0.2	
B. Layout of system in separate building			0.5	
C. Final choice of building design	0.1		0.1	
Task 4: Engine System Preliminary Design				
A. Design grid interconnection		0.3		0.8
B. Preliminary design analysis	0.2	1.7	0.7	
C. Perform system layout	0.5	2.0	0.9	
D. Schematic block diagrams of subsystems		1.5	1.0	
E. Material and process specifications		0.3	0.1	
F. Applicable material specifications		0.2	0.1	
G. Detailed procurement schedules		0.5	0.2	
H. Component test requirements		0.5		
I. Mockups	0.5			
Task 5: Firming up Commitments				
A. Update interconnect agreement	0.2			0.5
B. Update legal responsibilities of Clark	0.5			
C. Update approval on codes and regulations	0.2		0.1	
Task 6: Detailed Work Plan				
A. Update detailed work plan	1.0	0.7	0.2	
B. Cost estimates for work in subsequent phases	0.5	1.0	0.4	
Task 7: Decision to Implement				
A. Report to Clark Trustees on Tasks I-VI	0.5		0.1	
B. Decision of Trustees on implementation				
Task 8: Report to ERDA on Phase II				
A. Summary of Tasks 1-7	2.0 [†]	1.5 [†]		
B. Application of support for subsequent phases	1.0 [†]			
TOTAL	12.8	13.7	5.4	1.5

[†] Attributable to the demonstration aspects

Table 5.3-1

PHASE III: FINAL DESIGN AND RELATED ACTIVITIES

TASK DESCRIPTION	MAN MONTHS			
	CLARK	TECO	FITZ	NEES
Task 1: Engine System Design				
A. Design analysis, engine plant		2.5	1.0	
B. Flow diagram		2.0	0.8	
C. Detailed engine system layout and construction working drawings		4.0		
D. Detailed distribution system, building design and work drawings			3.0	
E. Mockup and models	0.5			
F. Procurement specifications		1.5	0.6	
G. Construction specifications		1.0	1.0	
H. Construction cost budget		0.7	0.5	
Task 2: Design of Monitoring System				
A. Design analysis, monitoring system	0.5 †			
B. Monitoring system layout and working drawings			0.5 †	
C. Procurement specifications	0.5 †			
D. Installation specifications	0.2 †			
E. Cost budget	0.1 †			
Task 3: Operations and Maintenance Procedures				
A. Specifications of procedures		1.5		
B. Operations and maintenance manual		1.2		
Task 4: Institutional Commitments				
A. Final resolution of legal issues relating to the Clark University Charter	0.5			
B. Final resolution of issues relating to code compliance, environmental impact	0.5			
C. Final resolution of financing issues	0.5			
Task 5: Grid Connection				
A. Final resolution of legal issues relating to the grid connection	0.5			
B. Final agreement on grid connection	0.5			0.5
C. Design of grid connection		2.0		0.5
Task 6: Design of energy conserving equipment required by ERDA, if any				
Task 7: Detailed Work Plan				
A. Detailed work plan for subsequent phases	0.5	0.2	0.1	
B. Update cost estimates for subsequent phases	0.2	0.2	0.1	
Task 8: Demonstration Information Program				
A. Prepare technical reports detailing regional and national implications of Phases I and II	2.0 †			
B. Prepare draft planning workbook on the Clark planning experience	2.0 †	1.0 †		
Task 9: Report to ERDA on Phase III				
A. Summary of tasks 1-8	1.5 †	1.0 †		
B. Application of support for subsequent phases	0.5 †			
TOTAL	11.0	18.8	7.6	1.0

Table 5.3-2

PHASE IV: CONSTRUCTION

TASK DESCRIPTION	MAN MONTHS				DOLLARS
	CLARK	TECO	FITZ	NEES	CONSTRUCTION/EQUIPMENT
Task 1: Construction Management Plan	0.3	1.3	0.6		
Task 2: Engine System Construction					
A. Building modification and site preparation		0.8	2.5		\$150,000
B. Equipment purchase and procurement	0.2	1.0	0.4		\$400,000
C. Component fabrication		0.3			
D. Install engine system		3.0	0.7		\$100,000
Task 3: Monitoring System Installation					
A. Equipment purchase and procurement	0.5 ⁺	0.5 ⁺			\$ 50,000 ⁺
B. Equipment installation	1.0 ⁺	0.5 ⁺			
Task 4: Grid Connection Installation					
A. Equipment purchase procurement		0.5		0.5	\$ 50,000
B. Component fabrication		1.0			
C. Equipment installation		1.0			
Task 5: Construction Reports					
A. Records and reports of deliveries		1.5 ⁺⁺	0.4 ⁺⁺		
B. Records of installation and construction systems		1.5 ⁺⁺	0.4 ⁺⁺		
C. Changes in drawings		2.5	0.8		
D. Daily construction log and photos		1.0 ⁺⁺	0.4 ⁺⁺		
Task 6: Demonstration Information Program					
A. Prepare press release informing local community of construction and implications	0.2 ⁺				
B. Prepare technical report on regional and national implications of final design adopted.	1.0 ⁺				
C. Final draft; planning workbook	1.0 ⁺	0.5 ⁺			
Task 7: Detailed Work Plan					
A. Detailed work plan, subsequent phases	0.5	0.5			
B. Update cost estimates for subsequent phases	0.5	0.5			
Task 8: Report to ERDA on Phase IV					
A. Summary of tasks 1-7	1.0 ⁺	0.5 ⁺			
B. Application for support in subsequent phases	1.0 ⁺				
++ TOTAL	7.2	18.4	6.2	0.5	\$750,000
++ Attributable in part to the demonstration aspects					

Table 5.3-3

PHASE V: STARTUP AND PERFORMANCE TESTS

TASK DESCRIPTION	MONTHS			
	CLARK	TECO	FITZMEYER	NEES
Task 1: Demonstration System Installation Test				
A. Engine system installation test	1.0 ⁺	3.0 ⁺⁺	1.5 ⁺⁺	
B. Monitoring system installation test	1.0 ⁺	0.5 ⁺		
C. Report to ERDA on installation tests	0.5 ⁺	0.2 ⁺		
Task 2: Startup Tests				
A. Engine system startup tests	1.0 ⁺⁺	1.0 ⁺⁺		0.5 ⁺
B. Monitoring system startup test	0.5 ⁺	0.5 ⁺	0.1 ⁺	
C. Report to ERDA on startup tests	1.0 ⁺	0.5 ⁺		
Task 3: Performance Tests				
A. Engine system performance test	1.0 ⁺	2.0 ⁺⁺		0.5 ⁺
B. Monitoring system performance test	1.0 ⁺	0.5 ⁺	0.1 ⁺	
C. Report to ERDA on performance tests	1.0 ⁺	0.5 ⁺		
Task 4: Demonstration Information Program				
A. Provide display facilities for demonstration system site visits by general public	2.0 ⁺			
B. Issue press release informing local community of system startup, availability of site visits	0.2 ⁺			
C. Publish technical report on monitoring and performance test, indicate implications of this on a regional and national basis. State results in terms of energy-economic models	1.5 ⁺	0.5 ⁺		
TOTALS	11.7	9.2	1.7	1.0

Table 5.3-4

PHASE VI: LONG-TERM OPERATION AND EVALUATION

TASK DESCRIPTION

MAN MONTHS PER YEAR

	CLARK	TECO	FITZ	NEES
Task 1. Monitoring system operation and maintenance.	2.0 [†]			
Task 2. Periodic reports to ERDA on engine system operation and maintenance.	1.0 [†]	0.5 [†]		
Task 3. Periodic reports to ERDA on monitoring system results.	0.5 [†]	0.3 [†]		
Task 4. Evaluation of Engine System operation and monitoring, report of same to ERDA.	0.5 [†]	1.0 [†]		
Task 5. Demonstration Information Program				
A. Issue periodic press releases to inform local community of demonstration system evaluation.	0.2 [†]			
B. Prepare technical publications for journals and conferences, indicating regional and local impact of system evaluation, state results in terms of energy-economic models.	3.0* [†]	1.0* [†]		
C. Update planning workbook.	1.0* [†]	1.0* [†]		
D. Continue site visit program as needed.	0.5 [†]			
FIRST YEAR TOTAL	8.7	3.8		
SUBSEQUENT YEARLY TOTAL	4.7	1.8		
FIVE YEAR TOTAL,	27.5	11.0		

*First year only.

Table 5.3-5

Table 5.3-6. Phase II Detailed Man Power Assignments

Individual	Position within component organization	Man months committed to each task								Total
		1	2	3	4	5	6	7	8	
<u>Clark University</u>										
Frank Puffer	Dean of Academic Affairs	.1	.2			.1		.1		.5
Lawrence Landry	Vice President for Business and Finance, Treasurer of the Trustees		.2	.1		.1		.1		.5
Robert Goble	Assistant Professor of Science, Technology, and Society	1.0	.9		.8	.4	.2	.1	2.0	5.4
Basil Kimball	Plant engineer		.1		.2					.3
Harry Schwarz	Professor of Environmental Affairs		1.5			.3	.3		.2	2.3
Chris Hohenemser	Professor of Physics						1.0	.2	.8	2.0
Albert Gottlieb	Assistant Professor of Physics	1.5								1.5
Robert Goodney	Director of Physical Plant		.1		.2					.3
<u>Thermo Electron Corporation</u>										
S.E. Nydick	Program Manager	.5			.5		.3		1.0	2.3
J.C. Sullivan	Consulting Mechanical Engineer	2.0		.5	3.0		.9		.5	6.9
T. Speidel	Senior Marketing Specialist	.5								.5
D. Lodding	Director of Administration Energy Systems						.5			.5
Designer					3.5					3.5
<u>Fitzemeyer and Tocci, Consulting Engineers</u>										
Ed Fitzemeyer	Senior Consulting Engineer	.6	.2	.8	3.0	.1	.6	.1		5.4
<u>New England Electric System</u>										
Ronald W. Plutnicki	Consumer Services Consultant	.2		.8		.5				1.5

Table 5.4-1: Total Costs

Phase	THOUSANDS OF DOLLARS				TOTAL
	Clark	TECO	Fitz	NEES	
II	65	79	37	4	185
III	54	109	51	3	217
IV	36	107	42	2	187
V	58	53	12	3	126
VI	139	64			203
Equipment					449
Civil work					92
Mech & Elec					131
Grid connect.					50
Monitoring					30
TOTAL					1,670

Table 5.5-1. Replication Cost Analysis

		MAN MONTHS		
		Engineering	Design	Supervision
1.0	Engineering and economic feasibility	1.0		
2.0	Detailed Engineering Study			
	Detailed layouts	0.5	1.0	
	Detailed cost analysis	0.7		
	Grid connection	0.3		
	Site and civil engineering	1.5	1.0	
	Environmental engineering	0.8		
	TOTAL	<u>3.8</u>	<u>2.0</u>	
3.0	Final Design			
	General arrangement drawings	1.0	2.0	
	Flow diagrams	1.0	1.5	
	Electrical drawings and layout	1.0	1.0	
	Thermal distribution system drawings & design	0.2	0.1	
	Heating and ventilation drawings and design	0.2	0.1	
	Structural and accoustics drawings and design	1.0	1.0	
	Engine system specifications	1.5		
	Electrical specifications	0.5		
	Structural and acoustics specifications	1.0	0.7	
	Heat and ventilation specifications	0.5		
	Thermal distribution system specifications	0.2		
	Project purchases, schedules and construction plan	1.5		
	Construction cost budget	0.5		
	TOTAL	<u>10.1</u>	<u>6.4</u>	
4.0	Installation			
	Engine installation			1.5
	Electrical installation			0.4
	Civil and architectural installation			1.5
	Heat and ventilation installation	1.0		0.2
	Thermal distribution installation			0.2
	Drawing changes	0.5	1.0	0.2
	TOTAL	<u>1.5</u>	<u>1.0</u>	<u>4.0</u>
5.0	Test and Startup	0.5		0.5
	GRAND TOTAL	15.9	9.4	4.5
	Total Engineering Cost		\$183,000	

REPLICATION COST ANALYSIS FOR CLARK ICES

Equipment and construction	\$672,000
Grid connection	50,000
Engineering	183,000
Lawyers, site evaluation	20,000
Instrumentation	<u>10,000</u>
TOTAL REPLICATION COST	\$935,000

TABLE 5.5-2
SUMMARY OF REPLICATION COSTS OF REPRESENTATIVE ICES

Manufac- turer	Elec- trical power ^a (MW)	Fuel oil type	Oil savings ^b (%)	Internal rate of return ^c (%/yr)	Capital cost ^d (\$1000)	Availability
Fairbanks Morse	1.5	#2	19	16	950	Production model
	1.3	#6	22	22	1000	Hypothetical mo- del, not confirmed
Superior	1.0	#6	17	18	1100	Modified production model, confirmed
Sulzer	3.0	#6	50	15	2050	Modified production model, confirmed

- a. Stated power level is maximum steady power level that can be produced by a given engine. Most engines can be run at about half of the stated level without serious loss of efficiency.
- b. Oil savings represent oil not needed at Clark or at the utility oil-fired power plants as a result of the proposed ICES. Percent savings are based on Clark's anticipated annual use of 30,000 bbls/yr.
- c. Internal rate of return gives payback realized before financing charges. It is based on the assumption that oil prices and all other prices escalate at 6% per year.
- d. Capital costs include engine price, engineering design, installation, and interconnect costs for heat recovery and grid connection. A new building would cost about \$180,000 more.

5.6 Demonstration and First-of-a-Kind Costs

Beyond the basic replication cost, full implementation of the R.F.P. involves two distinct aspects as follows.

(1) Demonstration costs. These are costs related to documenting actions taken, evaluating these actions, and reporting on this to ERDA and the general public. They include extensive monitoring, testing, evaluative report writing, and public information efforts. As shown in Table 5.6-1, these tasks account for \$470,000, nearly half of which would be expended in Phase VI: long term operation and evaluation.

(2) First-of-a-kind costs. These costs are related to engineering and institutional problems in constructing a first ICES. They are the most difficult to quantify explicitly in terms of phase schedules. We therefore obtain them by subtracting as follows.

First of a kind costs	Full R.F.P. = implementation	-	Replication costs	-	Demonstration costs
	= \$1,670,000	-	\$934,000	-	\$470,000
	= \$ 266,000				

Table 5.6-1. Demonstration levels of effort

Phase	M A N		M O N T H S	
	Evaluation & Reporting		Monitoring & Testing	Public Information
II	4.5			
III	3.0		1.3	5.0
IV	5.8		2.5	2.7
V	3.7		13.6	4.2
VI	12.5		16.5	9.5
Totals	29.5		33.9	21.4
Total cost	\$164,000		\$190,000	\$116,000
<hr/>				
All demonstration aspects	\$470,000			

5.7 Cost Summary

CLARK CONTRIBUTION

Engine system, including construction, installation, engineering, as outlined in Table 3.2-1.	\$820,000
--	-----------

ERDA CONTRIBUTION

Grid connection, system testing, explicitly stated as ERDA-supported in R.F.P. (When added to the Clark contribution, above, the result is the replication cost of the Clark ICES.)	114,000
--	---------

First-of-a-kind costs as outlined in Section 5.4	266,000
--	---------

Demonstration costs, as outlined in Section 5.4	470,000
---	---------

Total ERDA contribution, all phases	<u>\$850,000</u>
-------------------------------------	------------------

APPENDIX 1A

Monitoring Effort

A Heating Season Study of the Clark University Central Boiler Plant*

Robert W. Collins

Abstract. Using meters monitoring oil consumption at Clark University and a weather station monitoring the ambient temperature, a description and an analysis of the heating season energy consumption is undertaken. Energy consumption at the university as a function of time, temperature, and campus occupancy is described. Boiler efficiency and the central plant load curve are also calculated. With this data an energy balance equation for the university is constructed. Profiles of average inside temperature for the Clark complex are obtained from the balance equation and the effectiveness of nighttime turn-down is checked. This turn-down is found to be inadequate and recommendations are made to the university that could result in a 5% heating season fuel savings.

INTRODUCTION

In this work, an analysis of the heating season energy output of the central boiler plant at Clark University is undertaken. Diurnal profiles of energy output as a function of time of day and total daily energy output as a function of mean ambient temperature were measured. From these measurements a model of university energy use is constructed. The purpose of this study is to derive the average inside temperature of the university building complex as a function of time of day. Already, some of these results have helped determine the feasibility of cogeneration, electricity generation with heat recovery, for the Clark community.

At the outset, in Section I, the central plant and its monitoring system are described. The temperature monitoring apparatus based at Clark University is also described. To conclude Section I differences between the temperature measured at the university and the temperature measured at the Worcester airport by the National Weather Bureau are noted. In Section II diurnal profiles of central plant energy output as a function of time are exhibited for regular session weekdays and weekends and vacation weekdays and weekends. The dependence of the profiles on university occupancy and ambient temperature at the university is described. In Section III seasonal calculations are made. The plots of daily oil consumption vs mean ambient temperature in Section IIIA as well as generalizations of monthly ambient temperature distributions at the university determine the central plant heat load of Section IIIB. In Section IV monitoring data is used to calculate central plant boiler efficiency. In Section V the results of Section IIIA are used to develop an energy balance equation for the university. Energy input rates from oil consumption, solar insolation, occupants, and lighting are equated to the energy end-use rates: space heating, water heating, and transmission losses. To conclude Section V this equa-

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tion is solved, and the average inside temperature of the university complex as a function of time of day is derived using the profiles of Section II. The conclusions of the analysis of Section V are presented in Section VI. Nighttime turn-down is found to be ineffective, and estimates of possible fuel savings with proper turn-down are given.

I. APPARATUS AND DATA COLLECTION

The present central plant consists of three oil-fired boilers burning #6 and #2 fuel oil. The boilers convert to natural gas in late spring, and this remains the primary fuel until the fall. Two of these boilers are capable of producing steam at 16,000 lb/hr and the main boiler, call it boiler #3, is rated at 25,000 lb/hr. Pressurized steam is distributed from the central plant through underground lines to campus buildings where steam radiators, pressurized water heaters and absorption air conditioning equipment are in operation.

The main boiler has been fitted with three Hersey Niagara meters. These meters monitor total oil flow into the boiler, total return oil flow and feedwater flow. Each of the meters is equipped with transmitters that signal one of three counter/

FIG. 1: Main boiler monitoring apparatus.

totalizers after a fixed amount of oil or water has passed through the meter (see Fig. 1). In the case of the two oil flow meters, one count is registered at the respective totalizer after 10 gallons of oil have passed through the meter. One count is registered at the feedwater totalizer after 100 gallons have passed the meter. The totalizers add successive counts; the total number of counts from each totalizer is reset to zero after one hour has elapsed. The fractional count which has not registered at the end of the hour is not erased, but is included toward the first count of the next hour. Thus the uncertainty in the hourly water usage rate is ± 100 gal, and the uncertainty in each of the two oil flow rates is ± 10 gal/hr. To find the net oil consumption, the return oil flow rate is subtracted from the total oil flow rate, and the uncertainty here becomes ± 20 gal/hr. The column printer is set to print out the three rates on the hour.

Although the oil monitoring system has been in operation since February 24, 1977, water meter malfunction delayed the first feedwater monitoring day to March 18, 1977. Total daily oil consumption previous to February 14 was determined from the boiler logbook kept by the employees at the central plant. These were the only figures available at Clark University concerning the energy use of the central plant prior to the installation of the monitoring system. Fuel oil is stored in two 120,000 gallon underground tanks equipped with float meters, and tank volume is measured at the central plant at the start of each work shift. Oil usage over a 24 hour period from 23.00 to 23.00 of the following day is calculated using such data. Work shifts when fuel oil is delivered to the tanks (filling may take a period of hours), oil usage figures are not exact, and usage during tank filling is estimated. The inaccuracies inherent in reading the float meters result in daily usage uncertainties of as much as ± 250 gallons. In contrast, the uncertainty in daily oil consumption as measured by the flow meters is ± 20 gallons.

The apparatus at Clark University for weather monitoring consists of a platinum resistance thermometer and column printer which records the voltage across the temperature sensor on the hour. A constant current source is applied to the sensor and a calibration curve was constructed to convert the voltage drop across the sensor to ambient temperature. The calibration curve was obtained by comparison with a high accuracy mercury thermometer. The temperature monitor began operation on February 24. Subsequently other equipment monitoring wind speed and solar insolation have become operative. When daily temperature readings were needed for months previous to February or on days when the monitoring system was inoperative, data taken at the Worcester airport by the National Weather Bureau was utilized. The temperature at the airport tends to be lower than the temperature at Clark University. Daily maxima and minima fall on the same hour on roughly two out of three days. The aver-

FIG. 2: Ambient temperatures measured at Clark University and at the Worcester airport for a typical 42 hour period.

age difference between the temperature at the airport and the temperature at Clark University is 3.7°F (see Fig. 2) and the standard deviation of the difference from this value is $.5^{\circ}\text{F}$.

II. DIURNAL PROFILES

Since the oil flow meters have been monitoring the central plant for a longer period than the feedwater meter, demand profiles plot rate of oil consumption vs time of day. Because of the 20 gal/hr uncertainty in oil flow in comparison with typical oil consumption rates of 80 to 140 gal/hr for the monitoring months of February through April, it is necessary to average the hourly flow rates recorded at the column printer. A weighting function over a three hour period of recorded rates:

$$\bar{F}_{2n} = \frac{1}{2}(\frac{1}{2} F_{2n-1} + F_{2n} + \frac{1}{2} F_{2n+1}) \quad n = 1, 2, \dots, 12$$

averages out the fractional count ignored by the totalizer. Here F_i is the recorded flow rate for i th hour and $\bar{F}_i$ is the i th hour flow rate plotted in the profiles. These average flow rates are plotted at two-hour intervals.

It is found that the diurnal profiles are sensitive functions of three variables which are not themselves independent: (1) time of day, (2) ambient temperature, and (3) residential and academic area occupancy levels. The profiles are explicit functions of time of day; the effect of the latter two variables will be implicit in the following analysis.

FIG. 3: Ambient temperature and oil consumption as a function of time of day for the regular session weekday, March 7, 1977.

The following profiles are a result of monitoring boiler #3 only. At times of high demand, either of the lower-rated stand-by boilers may have been placed in operation as well. The profiles do not include oil consumption by boilers #1 or #2 since these figures are indeterminate until a complete central plant monitoring system is introduced.

In the following profiles total energy output is expressed by central plant oil consumption. Thus transmission losses through the lines and losses at the boiler through the stack are included in the total energy output. To obtain useful energy output the total output is multiplied by the efficiency of boiler #3, and transmission losses are subtracted out. To convert oil consumption to total energy output, the consumption is multiplied by the heating value of the fuel, 148,000 Btu/gal.

A. Regular Session Profiles of the Heating Season

In Fig. 3 oil consumption and ambient temperature vs. time of day is given for a typical regular session weekday of total residential occupancy. Such a form for the daily ambient temperature variation is typical of approximately four days out of five in the Worcester area. The temperature reaches its minimum daily value at 6.00 to 7.00, increases most rapidly in the morning hours to reach its maximum around midday, and decreases more slowly in the afternoon.

For this most common temperature pattern, the general features of the diurnal oil consumption profile are well understood. Early morning consumption is relatively flat for two reasons. First, the nighttime ambient temperature remains nearly con-

Table 1: Parameters of typical consumption profiles for regular session weekdays.

		Early morning plateau	Morning peak	Afternoon valley
Oil consumption rate (gal/hr)	3/9	105	104	58
Daily temperatures (°F)		37°	33°	60°
	3/28	105	130	85
		40°	39°	53°
	3/7	110	160	100
		33°	31°	35°
	3/22	115	140	90
		33°	31°	39°

stant and, secondly, campus activity is minimal. The morning demand peak occurs two hours after the ambient temperature minimum. The demand peak is due to the temperature minimum as well as the heat demand imposed by the increasing academic area occupancy. The afternoon minimum in oil consumption occurs two hours after the peak temperature. The second evening demand peak is a result of afternoon and evening temperature decline as well as increased residential occupancy and hot water usage by that sector. The evening demand peak is much broader than the morning demand peak due to a slower temperature drop than that in the morning, as well as varied lifestyles of the residential sector. These general features imply that the average time constant of the university complex is about two hours. To understand the origin of the time constant, imagine a situation in which the outside temperature, having been very warm, drops considerably at time 0.00. A great quantity of heat was stored in the physical structure of each of the campus buildings prior to the temperature decline. This heat will continue to warm the inside air of each structure for approximately two hours. Thus the increased rate of fuel consumption will be felt at approximately 2.00.

Six days were recorded "cleanly" in the case where the temperature variation was as described above. By "cleanly" it is meant that only boiler #3 was in operation throughout the day. Table 1 gives parameters of the profiles. These parameters reveal a general dependence of oil consumption rates on extremes of ambient temperature and indicate that the above analysis is correct.

An exception to the usual daily temperature variation and its effect on the consumption rate curve is shown in Figure 4. The midday temperature rise is negligible, and thus the afternoon minimum in the oil consumption curve does not occur. In fact, oil usage rate does not drop until an auxiliary boiler, boiler #1, is put

FIG. 4: Ambient temperature and oil consumption as a function of time of day for the regular session weekday, March 23, 1977.

FIG. 5: Ambient temperature and oil consumption as a function of time of day for the regular session weekend day, March 27, 1977.

into operation.

Generalizations of the profiles of weekend days during the regular session are made hesitantly due to the lack of "clean" curves. For weekend days, the early morning consumption curve is the same as that for a weekday. A comparison of the morning temperature variations in Figure 5 with that of March 22 in the preceding table shows that the early morning consumption profile maximum for a weekend day is reduced by 80% in comparison to a weekday of similar temperature. A second morning peak in oil consumption rate is evident and is presumed due to a hot water demand, as well as campus heating, since some buildings such as the library and campus dining halls open later on weekend mornings. The afternoon minimum of the weekend profile occurs as on a weekday but is deeper emphasizing (1) that it is the result of midday ambient temperature rise and (2) the fact that the academic sector needs less heat on these days.

B. Vacation Profiles of the Heating Season

The profiles for a typical vacation day are not much different from regular session days. Saturday vacation day profiles behave like weekdays while Sunday

FIG. 6: Ambient temperature and oil consumption vs time for the vacation weekday, March 3, 1977.

FIG. 7: Ambient temperature and oil consumption vs time for the vacation weekday, March 4, 1977.

vacation profiles are very flat.

A consumption profile for a typical vacation weekday is shown in Figure 6. The March 3 profile is typical of such days with the familiar diurnal temperature variation. The noticeable characteristic of this profile is the evening consumption rate peak. This is pronounced despite the near residential vacancy of the campus during vacation periods. It is apparent that this broad peak is due mainly to the nighttime ambient temperature decline. Thus it requires more heat to maintain the average inside temperature at its nighttime level than to maintain the average inside temperature at its afternoon level. This point will be considered in greater detail in Section VI.

The oil use profile of Figure 7 exhibits another exception to the common daily temperature variation. Instead of a temperature maximum near midday resulting in a consumption minimum two hours later, the reverse occurs. A temperature minimum strikes at midday along with a consumption maximum again over two hours later. The evening peak is not present due to an increasing nighttime temperature.

III. LONGER RANGE CALCULATIONS

A. Daily Oil Consumption as a Function of Temperature

In Figures 8, 9, 10 and 11, total daily oil consumption is plotted vs. the num-

FIG. 8: Total daily oil consumption vs degree days per day as measured at the Worcester airport. Each point represents a given weekday of the regular session.

FIG. 9: Total daily oil consumption vs degree days per day as measured at the Worcester airport for regular session weekend days.

FIG. 10: Total daily oil consumption vs degree days per day as measured at the Worcester airport for vacation weekdays.

FIG. 11: Total daily oil consumption vs degree days per day as measured at the Worcester airport for vacation weekend days.

ber of degree days measured at the Worcester airport for that day. The days are subdivided into four occupancy categories: regular session weekdays, regular session weekends, vacation weekdays, and vacation weekends, since each category has different energy end-use characteristics and occupancy patterns. The four figures correspond to the four categories respectively.

If the overall campus U-value⁽¹⁾ is independent of ambient temperature, these plots should be linear. Thus the straight lines shown in Figs. 8-11 are obtained by a linear regression analysis, and inspection of the fit shows that the above assumption is reasonable. Much of the scatter about the fitted lines can be attributed to the inherent inaccuracies in the logbook consumption data. However, taking into account the experimental uncertainties, there is still scatter about the fitted line. The causes of this scatter are now given. (1) The logbook records oil consumption from 23.00 of one day to 23.00 of the next day; this value is correlated with the degree day data of the second day. To be consistent with the two hour time constant of the university, oil consumption should be recorded from 2.00 to 2.00 of the following day. (2) Weather conditions other than ambient temperature, such as wind speed and solar insolation, affect the overall loss coefficient of the university. Analysis of the effects of these other variables has not been performed. (3) Degree day values are obtained from the National Weather Bureau using a daily mean temperature defined as the average of the minimum and maximum daily temperatures. Such a mean is not the true mean daily temperature, and its use may have a small effect on the data. (4) The degree day measurement is made at the Worcester airport and not at the university. To be correct, oil consumption by the central plant must be correlated with the number of degree days measured at the university. For the linearity of Figs. 8-11 to be preserved, the daily average temperature difference between the two locations must be constant. This is not strictly true as indicated at the end of Section I.

B. Central Plant Load

Much information about central plant loads can be deduced from Figs. 8-11. It is possible to calculate the number of hours in the Clark University heating season corresponding to a net energy demand above any fixed value. If one uses reasonable estimates of energy demand for the summer months of June, July, and August,⁽²⁾ this heating season load curve can be extended throughout the entire year. The annual load curve is an important result if Clark University should decide to install a total energy plant since in choosing among total energy plant alternatives, it sets the capacity and stand-by capability of the new system.

If one uses the linear fits of Figs. 8-11, the problem of calculating the heating season load curve reduces to finding the number of days of the heating

season such that

$$65^{\circ}\text{F} - T_m \geq T, \quad (3.1)$$

$T_m(^{\circ}\text{F})$ is the mean daily temperature measured at the university, and $T(^{\circ}\text{F})$ is any temperature less than 65°F . Define $G(T)dT$ as the amount of time within a fixed time period τ during which the ambient temperature lies between T and $T + dT$. Define $h(T)$ as the number of hours in the time period τ when the temperature is below T . Then it is clear that

$$h(T) = \int_{-\infty}^T G(T')dT'.$$

Work done by J. Davies⁽³⁾ indicates that the choice of a Gaussian form for $G(T)$ with $\tau = 1$ month is very reasonable. A Gaussian is chosen for each month centered about T_{av} , the average monthly temperature at Clark University. T_{av} is determined from data taken at the Worcester airport, adjusted to the ambient temperature at the university. Table 2 gives T_{av} , σ^2 , the variance, and τ for each month of the heating season. The Gaussian form for G implies that

$$\begin{aligned} h(T) &\approx \int_{-\infty}^T G(T')dT' = \frac{\tau}{\sqrt{2\pi\sigma^2}} \int_{-\infty}^T \exp\left(-\frac{(T' - T_{av})^2}{(\sqrt{2}\sigma)^2}\right) dT' \\ &= \frac{\tau}{2} \left(1 + \operatorname{erf}\left(\frac{T - T_{av}}{\sqrt{2}\sigma}\right)\right). \end{aligned} \quad (3.2)$$

Table 3 shows the results for $h(T)$ for each month using the above equation and the data given in Table 2. The data of Table 3 can be easily normalized to find the number of hours of regular session weekdays in each month when the temperature is below T . Since the academic calendar is known, the same can be done for regular session weekend days as well as vacation weekdays and weekend days. Finally the linear fits of Figures 8-11 are used to determine the number of hours within each of the four occupancy categories for each month when the oil consumption is above any particular value. The number of hours for each month is summed for each occupancy category, and the results are combined to obtain the heating season load curve.

In making this calculation, however, the linear fits of Figures 8-11 are modified to reflect the degree day values at the university rather than at the airport. The total daily oil consumption of Figs. 8-11 was also increased by 10% to include projected consumption due to the completion of the New Student Activities Center.

Due to the lack of data for the summer months the summer load curve can be only crudely estimated. The estimated average daily consumption rates are taken to be 800 gallons for weekdays and 650 gallons for weekend days. These two values are derived from an hourly base load consumption rate plus a contribution from absorption air conditioning. A twelve hour day from 6.00 to 18.00 is assumed with neg-

Table 2: T_{av} , the average monthly temperature, σ^2 , the variance, and τ , the length of the month for each month of the heating season.

	T_{av}	σ^2	τ
September	64.7°F	78.8°F ²	720 hr
October	55.3	93.2	744
November	43.6	109.4	720
December	30.9	102.3	744
January	27.3	154.7	744
February	28.8	116.7	672
March	37.0	96.5	744
April	49.0	132.9	720
May	59.5	99.4	744

Table 3: The function $h(T)$ evaluated at chosen values of T for each month of the heating season.

T	Sept h	Oct h	Nov h	Dec h	Jan h	Feb h	Mar h	Apr h	May h
3	0.	0.	0.	2.	18.	5.	0.	0.	0.
7	0.	0.	0.	6.	36.	14.	1.	0.	0.
11	0.	0.	1.	17.	68.	31.	3.	0.	0.
15	0.	0.	2.	41.	116.	64.	9.	1.	0.
19	0.	0.	6.	84.	182.	118.	23.	3.	0.
23	0.	0.	16.	155.	264.	193.	54.	8.	0.
27	0.	1.	38.	251.	357.	285.	109.	19.	0.
31	0.	4.	79.	366.	451.	384.	194.	40.	1.
35	0.	12.	142.	482.	540.	476.	304.	77.	5.
39	1.	32.	230.	580.	611.	552.	422.	134.	14.
43	5.	72.	334.	652.	664.	606.	535.	210.	35.
47	15.	138.	445.	700.	700.	639.	624.	303.	75.
51	41.	235.	541.	725.	722.	658.	683.	400.	141.
55	93.	354.	616.	737.	734.	667.	717.	495.	235.
59	181.	474.	666.	742.	740.	670.	734.	574.	348.
63	295.	580.	696.	743.	742.	671.	741.	636.	465.

ligible oil consumption at other times. To obtain the final annual load curve, the summer load is added to the heating season load and the final result is plotted in Fig. 12.

IV. BOILER EFFICIENCY CALCULATIONS

In order to develop a model for Clark University energy demand the efficiency of the main boiler must be known. With the present monitoring system the calculation becomes simple.

Feedwater enters the boiler at an average temperature of 205°F and emerges as dry saturated steam⁽⁴⁾ at an average gauge pressure of 120 psi. From standard steam tables,⁽⁵⁾ the enthalpy difference between these two thermodynamic states gives the

FIG. 12: The annual load curve of the central plant.

FIG. 13: Efficiency of boiler #3 as a function of feedwater intake.

amount of heat absorbed by the feedwater. Thus the boiler efficiency is given by:

$$\begin{aligned} \eta &= \frac{\text{heat absorbed by feedwater in a time interval } \Delta t}{\text{heating value of fuel consumed during } \Delta t} \\ &= \frac{(1019.3 \text{ Btu/lb})(8.0189 \text{ lb/gal}) \cdot W_{in}}{(148,000 \text{ Btu/gal}) \cdot F_{in}} = .0552 \frac{W_{in}}{F_{in}} \quad (4.1) \end{aligned}$$

where 8.0189 lb/gal is the density of water at 205°F, 1019.3 Btu/lb is the enthalpy difference, W_{in} is the flow rate of feedwater in gallons per hour, 148,000 Btu/gal is the heating value of the fuel, and F_{in} is the net fuel consumption in gallons of oil per hour. Feedwater inlet temperature may vary about the average by $\pm 5^\circ\text{F}$, but this variation implies an uncertainty in the enthalpy difference of ± 5 Btu/lb, an effect that is masked by the uncertainty in the fuel heating value. The output steam pressure also varies by ± 5 psi about the average; this effect is similarly masked by the uncertainty in fuel heating value.

Problems arise in calculating boiler efficiencies directly from the column printer at hourly intervals. As noted previously, the uncertainty in W_{in} is 100 gal/hr and the uncertainty in F_{in} is ± 20 gal/hr so that uncertainty in efficiency is as much as $\pm .25$. Consistent results are obtained by calculating the boiler efficiency over 6 hour time periods and maximum uncertainties of $\pm .02$ are introduced. Boiler efficiency for feedwater flow rates within 50 gal/hr intervals are averaged and plotted in Figure 13. Only flow rates with a sufficient number of efficiency meas-

urements are used in the plot in order to obtain a statistically accurate average. The boiler efficiency increases slightly with decreasing loads; for average loads the efficiency is .75.

V. ANALYSIS

The profiles of total oil consumption vs. time of day furnish no information about the demand of each of the various end-uses. Information of this type can be obtained from an analysis of the slopes and intercepts of Figs. 8-11.

When the average ambient temperature for a given day is 65°F , it is assumed that no space conditioning is needed for that day. This assumption should be justified since heat may be required in the morning and/or air conditioning in the afternoon, reflecting the daily maximum and minimum temperatures. However when the data in Figs. 8-11 was taken no absorption air conditioning equipment was in operation. Moreover, on days of average temperature greater than 65°F , the daily oil consumption matches that corresponding to zero daily degree days. Thus the ordinate intercepts of the linear fits of Figs. 8-11 represent oil consumption end-uses other than space heating and air conditioning. This base load includes water heating as well as efficiency and transmission line losses.

The slopes of the lines in Figs. 8-11 represent an overall campus U-value. Each slope can be interpreted as the additional oil (in gallons) consumed to heat the Clark complex of buildings to compensate for a daily mean ambient temperature drop of 1°F .

The total daily oil consumption in Figs. 8-11 can be separated into two components: consumption for space heating end-uses and consumption for other end-uses. $R_Q(t)$ in the following equation denotes the rate at which fuel must be supplied to the central plant for space heating end-uses only.

$$R_Q(t) = U\{T_{in}(t) - T_{out}(t - 2 \text{ hr.})\}; \quad T_{out} < 65^{\circ}\text{F} \quad (5-1)$$

$T_{in}(t)$ is the inside temperature averaged over the Clark complex at a time t , $T_{out}(t - 2 \text{ hr.})$ is the outside temperature 2 hours before time t , and the U-value is temperature independent. Here the two hour time constant of the University is indicated explicitly.

A further comment should be made concerning the U-value included in the above equation. As noted from the slopes of the lines fitting the data of Figs. 8-11, the U-value is a function of occupancy. Within experimental error regular session weekdays and weekend days exhibit the same U-value. U-values of vacation days are reduced by 15%. This is to be expected since, during the regular session when classes are held and students are active on campus, infiltration losses increase. The increased losses are a result of continual door and window opening in both the residential and

academic sectors of the university. From personal observation it is well known that dormitory rooms and classrooms are plagued by overheating and windows are opened often on the coldest of days. Thus it is reasonable to assume that the regular session U-value is a function of time of day, being the lowest from 1.00 to 7.00 and the highest from 9.00 to 19.00 when students are active on campus. The time averaged regular session U-value must then be the slope of the graphs of Figs. 8 and 9.

Equation (5-1) does not include other energy inputs and end-uses. Additional energy inputs include heat from lights, building occupants, and solar insolation and energy demands include water heating and transmission losses. If these inputs and end-uses are included and a time dependent U-value is assumed, the following equation results:

$$\begin{aligned} \eta R_{\text{tot}}(t) + I(t) + P(t) + L(t) = \eta U(t)\{T_{\text{in}}(t) - T_{\text{out}}(t - 2 \text{ hr.})\} + \eta W(t) + \eta X(t), \\ T_{\text{out}} < 65^{\circ}\text{F} \end{aligned} \quad (5-2)$$

where $R_{\text{tot}}(t)$ is the net rate at which fuel is supplied to the central energy plant. The quantities $\eta R_{\text{tot}}(t)$, $I(t)$, $P(t)$, and $L(t)$ represent rate of energy input from oil consumption, insolation, occupants and lights, respectively. The quantities $\eta U(t)\{T_{\text{in}}(t) - T_{\text{out}}(t - 2 \text{ hr.})\}$, $\eta W(t)$, and $\eta X(t)$ represent energy end-(use, misuse) rates: space heating, water heating and transmission losses, respectively.

The time variation of the average inside temperature, $T_{\text{in}}(t)$, would provide useful information about the effectiveness of nighttime shutdown. Although direct measurements of $T_{\text{in}}(t)$ are not available, $T_{\text{in}}(t)$ can be deduced from (5-2) if the parameters U, I, P, L, X, and W are known.

The U-value for vacation weekdays is 2.1 gallons of oil/day $\cdot^{\circ}\text{F}$ (see Fig. 10). This will be an assumed constant throughout the day, despite the fact that it might be slightly lower at night and higher during the day. If this variation is the case, the assumed constant U-value will make the calculated nighttime inside temperature lower than the actual temperature and the calculated daytime temperature higher, yielding conservative shutdown estimates. For regular session weekdays a base U-value of 2.1 gal oil/day $\cdot^{\circ}\text{F}$ for the hours 1.00 to 7.00 and a value of 2.4 gal oil/day $\cdot^{\circ}\text{F}$ for the hours 8.00 to 24.00 will be assumed. These values give a time average of U consistent with the slope in Fig. 8. This early morning U-value, 2.1 gal oil/day $\cdot^{\circ}\text{F}$ is used instead of the vacation weekend U-value, 2.0 gal oil/day $\cdot^{\circ}\text{F}$, for times of lowest campus activity since the data of Fig. 11 is not as extensive, and shutdown estimates will be again conservative.

Solar insolation, $I(t)$, is neglected in the analysis. This effect is negligible except between 10.00 and 15.00. If $I(t)$ is neglected, the calculated daytime inside temperatures on clear days might be lower than the actual temperatures.

Occupancy energy input, $P(t)$, is determined by occupancy levels. It is assumed

that each occupant is equivalent to an energy input rate of 100 Watts.⁽⁶⁾ Since the central plant boiler efficiency is 0.75, 375 occupants are equivalent to an additional input at the central plant of 1 gallon of oil per hour. The following occupancy levels are reasonable: vacation weekdays--600 occupants 9.00 to 17.00, negligible occupancy otherwise; regular session weekdays--2,000 occupants 9.00 to 17.00, 1,000 occupants otherwise.

The lighting input contribution toward space heating, $L(t)$, is closely tied to occupancy. The estimates of lighting can be made from profiles of electric power vs. time of day as well as data indicating electric power end-uses. Such data is available at the university.⁽⁷⁾ For a vacation weekday lighting provides a power input of about 300 kw between 9.00 and 17.00, whereas input is negligible at other times. For regular session weekdays this input is 500 kw from 8.00 to 22.00 and 200 kw otherwise. 50 kw of lighting is equivalent to an additional input at the central plant of 1 gallon of oil per hour.

Transmission line losses, $X(t)$, are obtained from an inspection of Figs. 8-11. Hot water usage on a vacation weekend day is negligible, so the ordinate intercept of Fig. 11 corresponds to transmission losses only. These losses amount to 42 gal oil/hr and are independent of time as well as session occupancy. The ordinate intercept for a vacation weekday is the same within experimental error as that for a vacation weekend day. Thus hot water usage, $W(t)$, is negligible for such days. The intercept of Fig. 8, for regular session weekdays, lies 300 gallons/day above that of Fig. 10 and 11. This represents daily oil consumption toward water heating. The actual time distribution of $W(t)$ for a regular session weekday is the weakest point in this analysis. It is reasonable to assume negligible hot water usage outside of the range from 7.00 to 23.00. During this time range, however, $W(t)$ is assumed constant. If $W(t)$ is not constant, the calculated inside temperature will be excessively high at times of maximum $W(t)$, and the calculated inside temperature will be low at times of minimum $W(t)$.

VI. RESULTS

The results of Section V are shown in Figs. 14 and 15 where the average inside temperature vs. time is given for vacation and regular session weekdays, respectively. The desired average inside temperature during the hours from 0.00 to 7.00 and from 19.00 to 24.00 is 55°F. However, an inspection of Fig. 14 shows that it is over 65°F. It is concluded that nighttime shutdown is only partially effective. This conclusion is supported by the pronounced evening demand peak shown in Fig. 6 and described in Section IIB. Overheating is also evident in Fig. 14 at times of highest demand (for the demand curve of this day see Fig. 6).

For the regular session weekday from 0.00 to 7.00, the desired average inside

FIGS. 14(top) & 15: Projected average inside temperature of the university vs time of day for the vacation weekday, March 4, 1977 (top), and for the regular session weekday, March 7, 1977.

temperature throughout the Clark complex is 57°F . This value results from a temperature of 55°F maintained within the academic area and a temperature of 60°F maintained within the dormitory area. The temperature from 19.00 to 24.00 depends on evening campus activities. From Fig. 15, the deduced average inside temperature from 0.00 to 7.00 is again above 65°F and ineffective nighttime shutdown is again implied. The temperature peak from 8.00 to 11.00 is believed to result from a combination of early morning overheating along with a peak in hot water usage, not included in the function $W(t)$ of the model. The temperature minimum at 13.00 to 14.00 is an effect of both solar insolation and a minimum in hot water usage, again not included in the model. It should be noted that the day of Fig. 14 was overcast whereas the day of Fig. 15 was clear. The excessively high temperature in the evening is also an effect of hot water usage. The inadequacies in accounting for daytime and evening temperature levels is attributed only to a lack of knowledge of $W(t)$ and $I(t)$ in the model. The conclusions concerning nighttime shutdown are dependable.

Using the model described above an estimation of hourly oil savings can be made if proper nighttime shutdown is effective. R_Q , the rate of oil consumption for space heating end-uses, can be found from a comparison of Eqs. (5-1) and (5-2). The value of R_Q from Eq. (5-1) for the calculated nighttime temperatures can be compared with that of the ideal nighttime temperatures, 55°F for a vacation weekday and 57°F for a regular session weekday. The difference is the possible hourly savings. The results of this calculation are 25 gal oil/hr and 20 gal oil/hr for the days of Figs. 14 and 15, and thus daily savings are approximately 250 gallons and 120 gallons respectively. Calculations of this kind show that a 5% reduction in heating season fuel costs can be realized solely through proper shutdown for the hours described above. Confidence in this estimate arises from the conservative assumptions used to obtain it. In conclusion, assuming the current price of oil, an annual savings of \$12,000 would be realized if IBM System 7, the central plant control computer, were programmed to effect proper shutdown.

FOOTNOTES

- (1) The U-value is a measure of the magnitude of the heat losses from the university structure due to conduction, convection, radiation and infiltration. A more specific definition is given in Section V.
- (2) Monitoring data is not yet available for these months.
- (3) L. Hanners and J. Davies, STS Rev. 2, 9 (1976).
- (4) Very small amounts of water vapor may be present in the steam. One way to determine if such vapor is present is to calculate efficiencies using the method described here then compare it with the efficiencies calculated by a measurement of stack gas composition. In any event, this has not been carried out, and uncertainties are thus not included in the efficiency calculations.
- (5) Keenan, J.H. and Keyes, F.G., Thermodynamic Properties of Steam, John Wiley and Sons, New York, 1936.
- (6) ASHRAE Handbook of Fundamentals, American Society of Heating Refrigerating, and Air-Conditioning Engineers, Inc., New York, 1972, p. 124.
- (7) See R. Collins, R.L. Goble and A.M. Gottlieb, this issue, Fig. 4.

APPENDIX 1B

Present Electric Rate Schedule

APPENDIX 1B

MASSACHUSETTS ELECTRIC
COMPANY

OPTIONAL LARGE-POWER RATE H
CLARK UNIVERSITY

AVAILABILITY

This rate is available for all purposes except resale. All service delivered at a given location shall be billed hereunder, and all charges shall be based on a Demand of 500 kilowatts or more. If delivery is through more than one meter, except at the Company's option, the Monthly Charge for service through each meter shall be computed separately under this rate.

MONTHLY CHARGE

The Monthly Charge will be the sum of the Demand and Energy Charges.

Demand Charge

\$700.00 for the first 500 kilowatts or less of Demand,
\$ 1.30 per kilowatt of Demand in excess of 500 kilowatts.

Energy Charge

2.317 ¢ per kilowatt-hour for the first 50,000 kilowatt-hours,
2.017 ¢ per kilowatt-hour for the next 50,000 kilowatt-hours,
1.707 ¢ per kilowatt-hour for the excess over 100,000 kilowatt-hours.

Notwithstanding the foregoing, the following reduced prices shall apply:

1.597 ¢ per kilowatt-hour for all kilowatt-hours in excess of 200 kilowatt-hours per kilowatt of Demand,
1.137 ¢ per kilowatt-hour for all kilowatt-hours in excess of 300 kilowatt-hours per kilowatt of Demand,
1.037 ¢ per kilowatt-hour for all kilowatt-hours in excess of 400 kilowatt-hours per kilowatt of Demand,
0.987 ¢ per kilowatt-hour for all kilowatt-hours in excess of 500 kilowatt-hours per kilowatt of Demand.

PURCHASED POWER COST ADJUSTMENT

The prices under this rate as set forth under "Monthly Charge" may be adjusted from time to time in the manner provided in the Company's Purchased Power Cost Adjustment Provisions to reflect changes occurring on or after January 1, 1971 in the Primary Service for Resale Rate of the Company's supplier, New England Power Company.

ADJUSTMENT FOR COST OF FUEL

The amount determined under the preceding provisions shall be adjusted in accordance with the Company's Standard Fuel Clause as from time to time effective in accordance with law.

DEMAND

The Demand for each month under ordinary load conditions shall be the greatest of the following:

- a) The greatest fifteen-minute peak occurring during such month as measured in kilowatts,
- b) 80% of the greatest fifteen-minute peak occurring during such month as measured in kilovolt-amperes,
- c) 80% of the greatest Demand as so determined above during the preceding eleven months,
- d) 500 kilowatts.

Any Demands established during the eleven months prior to the application of this rate shall be considered as having been established under this rate.

INCREASED NIGHT USE

If a Customer has entered into a five-year agreement for electric service guaranteeing that the Demand shall be not less than 500 kilowatts and guaranteeing to pay for not less than 200 kilowatt-hours per kilowatt of Demand each month, then any fifteen-minute peaks occurring during the periods from 10:00 P.M. to 7:00 A.M. daily and from 7:00 A.M. to 10:00 P.M. on Sundays and legal holidays in Massachusetts shall be reduced by one-half for the purpose of ascertaining the Demand as defined above. On one week's notice to the Customer the Company may change the hours specified above provided that the aggregate weekly number of hours be not decreased.

For a Customer using the Increased Night Use provisions and taking auxiliary service, the minimum Demand under Auxiliary Service provisions shall be 40% of the kilovolt-ampere rating of the transformers through which service is furnished, whether such transformers be supplied by the Company or the Customer, or, if service be not furnished through separate transformers, 40% of the kilovolt-ampere rating of the standard size of transformers which would be required for such service. In no case shall the monthly Demand be less than 500 kilowatts.

HIGH VOLTAGE METERING ADJUSTMENT

The Company reserves the right to determine the metering installation. Where service is metered at the Company's supply line voltage, in no case less than 2400 volts, thereby saving the Company transformer losses, a discount of 2½% will be allowed from the amount determined under the preceding provisions.

CREDIT FOR HIGH VOLTAGE DELIVERY

If the Customer accepts delivery at the Company's supply line voltage, not less than 2400 volts, and the Company is saved the cost of installing any transformer associated equipment, a credit of 12 cents per kilowatt of billing demand for such month shall be allowed against the amount determined under the preceding provisions.

TERM OF AGREEMENT

The agreement for service under this rate will continue for an initial term of one year if electricity can be properly supplied to a Customer without an uneconomic expenditure by the Company. The agreement may be terminated at any time on or after the expiration date of the initial term by twelve months' prior written notice.

TERMS AND CONDITIONS

The Company's Terms and Conditions in effect from time to time, where not inconsistent with any specific provisions hereof, are a part of this rate.

APPENDIX 1C

Candidate System Performance and Cost Estimates

Appendix 1C

Abstract

In this appendix we present in detail our analyses of candidate system performance and our cost estimates. In section 1C.1 we present heat balances for the engines listed in Table 1.5.3-1 of the main text. The figures include incremental fuel costs for operating the systems: fuel cost/kwh less credit for the heat produced. In section 1C.2 we present detailed estimates of installed costs for the same systems.

1C.1 Performance of the Demonstration Systems

For each diesel generator and gas turbine considered, heat balance data were obtained from the engine manufacturer in terms of Btu per bhp-hr. The heat balance parameters given by the manufacturer were:

- Work Output
- Jacket Water
- Lubricating Oil Cooling
- Exhaust Gases
- Exhaust Latent Heat
- Radiation and Unaccounted

Exhaust gas flows and exhaust gas temperatures were also obtained from the engine manufacturer for each engine evaluated. This data was then used to obtain system heat balances, showing the amount of 125 psig and 15 psig (or water cooling) steam flows.

A characteristic of diesel engines is that performance (i.e. heat balance in terms of Btu/kwh) is fairly constant down to about 50% of design load and then drops off substantially. Electricity output and the general performance of diesels are less sensitive to ambient temperature variations than gas turbines.

Noncondensing and extraction condensing steam turbines were considered with maximum steam-flows of 16,000 and 32,000 lb/hr. Electricity

outputs are 365 and 904 kw respectively at these steam flows. Part load performance for these two turbine sizes is shown in Figure 1C-1 (Kw Output vs. Steam Flow), Figure 1C-2 (Heat Rate vs. Steam Flow), and Figure 1C-3 (Fuel Cost vs. Steam Flow). As a result of the poor efficiency of the turbines below 75% of maximum output, very little power is produced with these turbines. In fact, the electrical output goes to zero at about a half of maximum steam flow. Theoretically, the heat rate of noncondensing turbines should be independent of steam flow and equal to $(1/\eta_b \times \eta_G) \times 3413$; η_b = boiler efficiency and η_G = electrical generator efficiency). However, as a result of the loss of enthalpy due to blowdown for about 5% of the steam produced and an assumed 5% make-up, the heat rate increases with a decrease in steam flow. The heat rate, in fact, will go to infinity, as electrical output goes to zero, since even at zero electrical output, fuel is required for blowdown and make-up. Of course, one would not operate the turbine down to the steam flow where the electrical output vanishes, limiting operation of the steam flow when the incremental heat rate approaches 10-15,000 Btu/Kwh. The total electricity that can be produced at Clark is greater for the 365 Kw turbine than for the 904 Kw turbine as a result of the predominance of steam demand in the 8,000-16,000 lb/hr range.

Automatic extraction/condensing turbines were selected for an output to the heating system of 16,000 lb/hr and 32,000 lb/hr with throttle flows of 23,000 lb/hr and 34,000 lb/hr. The performance of the smaller system is shown in Figure 1C-4. For reasons similar to those given for the noncondensing turbine, the larger, extraction/condensing turbine will result in less total power produced at Clark than the smaller system.

The extraction/condensing turbine can be thought of as the superposition of a turbine operating from throttle pressure to condensing and another operating from throttle pressure to a positive back pressure. Thus, the heat rate for the extraction/condensing turbine will always be worse than that for a noncondensing turbine since the heat rate for the condensing part of the turbine will be at best for a small, 600 psig system 15,000-17,000 Btu/Kwh.

For each candidate system, the following assumptions were used to

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Noncondensing Turbine EKW Versus Throttle Flow
FIGURE 1C-1

Noncondensing Turbine Heat Rate Versus Throttle Flow
FIGURE 1C-2

Noncondensing Turbine Fuel Cost Versus Throttle Flow
FIGURE 1C-3

Condensing Automatic Extraction Turbine

FIGURE 1C-4

determine the heat balance.

1. The deaerator in the existing heating plant was used.
2. The boiler blowdown was taken to be 5%.
3. 95% of the steam was returned. The return temperature was 160°F. The makeup water temperature was 60°F.
4. The final feedwater temperature was 225°F.
5. The boiler exit gas temperature for fired and heat recovery boilers was fixed at 325°F. The following diesel generators were evaluated with ebullient cooled jackets.

Case IV Fairbanks-Morse 1531 Kw Diesel

Case V Fairbanks-Morse 850 Kw Diesels

Case VII Caterpillar 700 Kw Diesel

Case IX Sulzer Model Z-40 3030 Kw Diesel

An analysis of the campus heating system showed that the maximum average low pressure steam duty which could be utilized by the heating system was 2.4×10^6 Btu/hr. All other diesels used water cooling systems.

6. The average heat used from a water cooled jacket was no more than $.35 \times 10^6$ Btu/hr. The average heat used from an ebulliently cooled jacket was no more than 2.4×10^6 Btu/hr.
7. For the reasons discussed in Section 1.5, the efficiency of the conventional system was taken to be 85%.

Figure 1C-5 is a schematic for the heat balance calculation using a diesel as an example.

The heat rate for the engine was calculated by comparing the fuel requirements for the proposed demonstration system with those for the conventional system. The fuel to the engine per Kwh is:

$$\text{EHR} = \frac{\text{lb fuel}}{\text{bhp-hr}} \times \frac{1}{.746} \times \text{heating value (Btu/lb fuel)} \quad (1)$$

where

EHR = engine heat rate (Btu/Kwh)

The total fuel per Kwh used by the proposed system is then obtained by adding boiler fuel used to supplement the engine thermal output:

$$\frac{H_{ds}}{\epsilon_T} = \text{EHR} + \frac{H_b}{\eta_b \epsilon_T} \quad (2)$$

where

Fig. 1C-5

H_{ds} = total fuel used by demonstration system (Btu/hr)

H_b = thermal output of supplemental boiler (Btu/hr)

ϵ_T = electricity produced by engine (Kw)

The total fuel used by the conventional system is just the boiler fuel required to obtain the required thermal output.

$$H_{cs} = \frac{H_b + H_t}{\eta_b} \quad (3)$$

Subtracting equations 2 and 3 then results in the desired incremental heat rate:

$$\begin{aligned} HR &= EHR + \frac{H_b}{\eta_b \epsilon_T} - \frac{H_{cs}}{\epsilon_T} \\ &= EHR + \frac{H_t}{\eta_b \epsilon_T} \end{aligned} \quad (4)$$

We see from equation 4 that the term H_t/η_b is the useful thermal output (from the exhaust and cooling jacket) generated by the diesel which replaces boiler fuel which would have had to be utilized in a conventional boiler. This fuel is therefore credited to the diesel. A derivation of the incremental heat rate for a gas turbine and noncondensing and extraction/condensing steam turbines would result in expressions identical to equation 4.

Another key parameter is the cost of fuel attributable to generation of electricity. This is the cost of fuel for running the system less the cost of fuel that would be used in the existing boiler to make up the heat output of the candidate system. This can be expressed

$$fc_T = f_e \times EHR - \frac{f_b \times H_t}{\eta_b \epsilon_T} \quad (5)$$

where

fc_T = cost of fuel attributable to generation of electricity ($\$/Kwh$)

f_e = price of fuel used in engine ($\$/10^6$ Btu)

EHR = fuel input to engine (or high pressure boiler for a steam turbine) (Btu/Kwh)

f_b = price of fuel that would be used in a conventional boiler ($\$/10^6$ Btu)

H_t = useful thermal output of system (Btu/hr)

η_b = efficiency of conventional boiler

The derivation of equation 5 is similar to that for the heat rate, equation 4. When the same type of fuel is used for both the engine and the boiler, or when the costs for these fuels are equal, fc_T is simply the fuel cost multiplied by the heat rate.

Table 1C-1 shows a convenient comparison of the performance of the demonstration systems considered. We see from this table that the Sulzer 3030 kw and the Caterpillar 700 kw engines have the lowest incremental heat rate based on actual heat used. The Sulzer, however, has the lower incremental fuel cost since it is residual fuel whereas the Caterpillar is distillate fuel. The Pielstick 4550 kw produces the greatest thermal and electrical output at full load followed by the Sulzer 3030 kw engine.

The heat balances themselves are shown in Figures 1C-6 to 1C-21.

1C.2 Capital Costs for Candidate Systems

Capital costs for candidate systems were estimated for two cases: installation inside Jonas Clark, and installation in a new building constructed for that purpose. The capital costs for all the demonstration systems considered are shown in Table 1C-2 for installation inside Jonas Clark. Table 1C-3 shows capital costs for installation inside and outside Jonas Clark for several demonstration systems.

Capital costs fall into three main categories: equipment, installation, and engineering costs. Installation costs fall into three sub-categories: civil work, mechanical work, and electrical work.

Equipment costs are based on manufacturer's quotations, except as noted. Civil work, mechanical work, electrical work, and engineering costs are based on detailed cost estimates for the labor of installation.

I. Equipment Costs

- a. The engine cost includes generator and switchgear as quoted by the manufacturer. This cost includes all accessory equipment required to make the engine operational. Spare parts are not included.

DETAILED PERFORMANCE DATA

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Case No.	System Description	Fuel Oil Type	Power Output ekw	Steam Generated			Incremental Heat Used		Fuel Cost Actual \$/kWh	Electrical/Steam				Heat Balance						
				H. P.	L. P. lbs/hr	L. P. Used	All Jacket Heat Used Btu/kWh	Actual Jacket Heat Used Btu/kWh		Generated		Used		Fuel	Power	Jacket	Exhaust	Lube Oil	Air Cooler	Radiation
										kWh/lb	kWh/1000 Btu	kWh/lb	kWh/1000 Btu							
I	2 GM Diesels, 870 kW Each	No. 2	1740	2664	4853	341	4805	7935	0.02487	0.2314	0.2132	0.5790	0.4932	6894	2545	2077	1938	-	-	334
II	1 GM Diesel, 2210 kW	No. 2	2210	4308	6042	341	4399	7512	0.02384	0.2135	0.1949	0.4753	0.4025	6931	2545	2033	2269	-	-	84
III	1 GM Diesel, 1780 kW	No. 2	1780	3638	4863	341	3716	6853	0.02367	0.2094	0.1908	0.4473	0.3795	7080	2545	2030	2421	-	-	84
IV	1 FMOP Diesel, 1531 kW	No. 2	1531	2983	979	979	6596	6596	0.02134	0.3864	0.3358	0.3864	0.3358	6555	2545	465	2230	775	400	140
V	2 FMOP Diesels, 850 kW Each	No. 2	1700	3430	2034	2034	7065	7065	0.02318	0.3111	0.2751	0.3111	0.2751	7366	2545	870	2430	1330	-	191
VIa	2 Sulzer Diesels, 780 kW Each	No. 2	1560	2770	2144	341	6190	7585	0.02400	0.3174	0.2834	0.5014	0.4268	6725	2545	996	2143	379	522	140
VIb	3 Caterpillar Diesels, 700 kW	No. 2	1400	2080	3300	2339	5658	6482	0.02161	0.2602	0.2386	0.3168	0.2868	7553	2545	1718	2033	753	-	304
VII	1 Colt Pielstick, 4550 kW	No. 6	4550	9779	5945	2339	5798	6755	0.01689	0.2894	0.2561	0.3755	0.3235	6730	2545	897	2338	215	520	215
VIII	1 Enterprise Diesel, 2591 kW	No. 6	2591	5447	3285	341	6222	7593	0.01898	0.2967	0.2626	0.4476	0.3784	6934	2545	922	2323	305	603	236
IX	1 Sulzer Diesel, 3030 kW	No. 6	3030	5419	3060	2339	6194	6481	0.01020	0.3574	0.3155	0.3906	0.3418	6564	2545	748	2169	322	634	146
Xa	1 Noncondensing Steam Turbine, 904 kW	No. 6	904	32000	-	-	6623	-	0.01656	0.0283	0.02368	0.0283	0.02368	-	-	-	-	-	-	-
Xb	1 Noncondensing Steam Turbine, 904 kW	No. 6	365	16000	-	-	7380	-	0.0185	0.0228	0.01812	0.0228	0.01812	-	-	-	-	-	-	-
XIa	1 Steam Turbine Condensing 1035 kW	No. 6	1035	32000	-	-	10296	-	0.0257	0.03234	0.02711	0.03234	0.02711	-	-	-	-	-	-	-
XIb	1 Steam Turbine Condensing, 1035 kW	No. 6	935	16000	-	-	12721	-	0.032	0.0647	0.0467	0.0647	0.0467	-	-	-	-	-	-	-
XIIa	2 International Harvester 800 kW Solar Gas Turbines (70°F)	No. 2	800	5194	-	-	8148	-	0.0285	0.154	0.1291	0.154	0.1291	-	-	-	-	-	-	-
XIIb	2 International Harvester 800 kW Solar Gas Turbines (90°F)	No. 2	700	5863	-	-	6707	-	0.0253	0.1194	0.10008	0.1194	0.10008	-	-	-	-	-	-	-

Notes: Residual Oil (No. 6) - 2, 50/10⁶ Btu
 Distillate Oil (No. 2) - 3, 00/10⁶ Btu
 Convective Boiler Efficiency - 85%

Table 1C-1

FIGURE 1C-6

$$\text{HEAT RATE}_1 = \frac{1200 \times .379 \times 19,280 - \frac{1334 \times 1193 - 1484 \times 121.9 + 2.49 \times 10^6}{.85}}{870} = 4805 \text{ BTU/KWH}$$

$$\text{HEAT RATE}_2 = \frac{1200 \times .379 \times 19,280 - \frac{1334 \times 1193 - 1484 \times 121.9 + 0.175 \times 10^6}{.85}}{870} = 7935 \text{ BTU/KWH}$$

$$\text{FUEL COST}_2 = \frac{1200 \times .379 \times 19,280 \times \$3.00/10^6 - \left[\frac{1334 \times 1193 - 1484 \times 121.9 + 0.175 \times 10^6}{.85} \right] \times 2.50/10^6}{870} = \$0.2487/\text{KWH}$$

THERMO ELECTRON ENGINEERING CORPORATION 85 FIRST AVENUE • WALTHAM, MASS. 02184			
DRAWN	CHECKED	ENGINEER	
P. Grew	Det	Det	
TITLE: CASE I G-M DIESEL 720 RPM, 8 CYL, 870 KW 1200 BHP, MODEL 8E4			
SIZE	DRAWING NUMBER	SHEET	REV
A			

FIGURE 1C-7

$$\text{HEAT RATE}_1 = \frac{3055 \times .38 \times 19,280 - \frac{4308 \times 1193 - 4507 \times 127.9 + 6.2 \times 10^6}{.85}}{2210} = 4399 \text{ BTU/KWH}$$

$$\text{HEAT RATE}_2 = \frac{3055 \times .38 \times 19,280 - \frac{4308 \times 1193 - 4507 \times 127.9 + 35 \times 10^6}{.85}}{2210} = 7512 \text{ BTU/KWH}$$

$$\text{FUEL COST}_1 = \frac{3055(.38)(19,280) + (3.00/10^6) - \left[\frac{4308 \times 1193 - 4507 \times 127.9 + 35 \times 10^6}{.85} \right] \times 2.5/10^6}{2210} = \$0.2384/\text{KWH}$$

THERMO ELECTRON ENGINEERING CORPORATION 85 FIRST AVENUE • WALTHAM, MASS. 02154			
DRAWN	CHECKED	ENGINEER	
P. Gtelo	JCS	JCS	
TITLE: CASE II MODEL SZO EA GM DIESEL 720 RPM, 20 CYLS 3055 BHP 2210 EKW			
SIZE	DRAWING NUMBER	SHEET	REV
A			

FIGURE 1C-8

$$\text{HEAT RATE}_1 = \frac{2460 \times .383 \times 19,280 - \frac{3638 \times 1193 - 3838 \times 127.1 + 4.99 \times 10^6}{.85}}{1780} = 3716 \text{ BTU/KWH}$$

$$\text{HEAT RATE}_2 = \frac{2460 \times .383 \times 19,280 - \frac{3638 \times 1193 - 3838 \times 127.1 + .35 \times 10^6}{.85}}{1780} = 6853 \text{ BTU/KWH}$$

$$\text{FUEL COST}_2 = \frac{(2460 \times .383 \times 19,280) \$3.00/10^6 - \left[\frac{3638 \times 1193 - 3838 \times 127.1 + .35 \times 10^6}{.85} \right] \$2.5/10^6}{1780} = \$0.02367/\text{KWH}$$

THERMO ELECTRON ENGINEERING CORPORATION 85 FIRST AVENUE • WALTHAM, MASS. 02154		
DRAWN	CHECKED	ENGINEER
P. Gero	Yes	Yes
TITLE: CASE III GM DIESEL 720 RPM, 16 CYL, 1780 EKW 2460 BHP. MODEL 316E4		
SIZE	DRAWING NUMBER	SHEET REV
A		

FIGURE 1C-9

$$\text{HEAT RATE} = \frac{2160 \times .36 \times 19,280 - \frac{2983 \times 1193 - 3133 \times 127.5 + 1.00 \times 10^6}{0.85}}{1531} = 6596 \text{ BTU/KWH}$$

$$\text{FUEL COST} = \frac{2160 \times .36 \times 19,280 \times \$3.00/10^6 - \left[\frac{2983 \times 1193 - 3133 \times 127.5 + 1.0 \times 10^6}{.85} \right] \$2.5/10^6}{1531} = \$0.02139 / \text{KWH}$$

THERMO ELECTRON ENGINEERING CORPORATION 85 FIRST AVENUE - WALTHAM, MASS. 02154		
DRAWN	CHECKED	ENGINEER
P. GREGO	JES	JES
TITLE: CASE IV F-M.O.P. - 9 CYL. MOD. 38 TO 8 1/8 2160 3 HP 720 RPM EKW = 1531		
SIZE	DRAWING NUMBER	SHEET REV
A		

FIGURE 1C-10

$$\text{HEAT RATE} = \frac{1200 \times .405 \times 19,280 - \frac{1715 \times 1193 - 1815 \times 126.7 + 1.044 \times 10^6}{.85}}{850} = 7065 \frac{\text{BTU}}{\text{KWH}}$$

$$\text{FUEL COST} = \frac{1200 \times .405 \times 19,280 \times \$3.00/10^6 - \left[\frac{1715 \times 1193 - 1815 \times 126.7 + 1.044 \times 10^6}{.85} \right] \times \$2.50/10^6}{850} = \$0.2318/\text{KWH}$$

THERMO ELECTRON ENGINEERING CORPORATION 65 FIRST AVENUE • WALTHAM, MASS. 02154			
DRAWN	CHECKED	ENGINEER	
S BUCZAK			
TITLE: CASE V F-M O.P. DIESEL 900 RPM, 6 CYL, 850 KW 1200 BHP, MODEL 38D8-1/8			
SIZE	DRAWING NUMBER	SHEET	REV

► TO HEATING SYSTEM

THERMO ELECTRON ENGINEERING CORPORATION 85 FIRST AVENUE • WALTHAM, MASS. 02154			
DRAWN	CHECKED	ENGINEER	
P. Greco	<i>[Signature]</i>	<i>[Signature]</i>	
TITLE: CASE VI SULZER MODEL NO. ASL25/30 780 KW-1100 BHP-6 CYL. 750 R.P.M.			
SIZE	DRAWING NUMBER	SHEET	REV
A			

FIGURE 1C-12

 THERMO ELECTRON ENGINEERING CORPORATION 85 FIRST AVENUE • WALTHAM, MASS. 02154			
DRAWN	CHECKED	ENGINEER	
P. Grelco	<i>[Signature]</i>	<i>[Signature]</i>	
TITLE: CASE VI B CATERPILLAR D399 985 BPH, 1200 RPM EKW = 700			
SIZE	DRAWING NUMBER	SHEET	REV
A			

FIGURE 1C-13

$$\text{HEAT RATE}_1 = \frac{6420 \times .379 \times 18,799 - \frac{(9779)(1193) - 10,279 \times 127.4 + 6.1 \times 10^6}{0.85}}{4550} = 5798 \text{ BTU/KWH}$$

$$\text{HEAT RATE}_2 = \frac{6420 \times .379 \times 18,799 - \frac{(9779)(1193) - (10,279)(127.4) + 2.4 \times 10^6}{.85}}{4550} = 6755 \text{ BTU/KWH}$$

$$\text{FUEL COST}_2 = 6755 \text{ BTU/KWH} \times \$2.50/10^6 \text{ BTU} = \$0.01689/\text{KWH}$$

THERMO ELECTRON ENGINEERING CORPORATION 85 FIRST AVENUE • WALTHAM, MASS. 02154			
DRAWN	CHECKED	ENGINEER	
P. GREGG	J. S.	J. S.	
TITLE: CASE VII COLT-PIELSTICK MODEL 12 PC2V 12 CYL. 514 RPM 6420 B HP - EKW = 4550			
SIZE	DRAWING NUMBER	SHEET	REV.
A			

FIGURE 1C-14

$$\text{HEAT RATE}_1 = \frac{3656 \times .391 \times 18,799 - \frac{5447 \times 1193 - 5746 \times 127.0 + 3.37 \times 10^6}{.85}}{2591} = 6222 \text{ BTU/KWH}$$

$$\text{HEAT RATE}_2 = \frac{3656 \times .391 \times 18,799 - \frac{5447 \times 1193 - 5746 \times 127.0 + 0.35 \times 10^6}{.85}}{2591} = 7593 \text{ BTU/KWH}$$

$$\text{FUEL COST}_2 = 6593 \times \$2.50/10^6 = \$0.01698 / \text{KWH}$$

<p>THERMO ELECTRON ENGINEERING CORPORATION 85 FIRST AVENUE • WALTHAM, MASS. 02154</p>			
DRAWN	CHECKED	ENGINEER	
P. GREGO	J. L.	J. L.	
TITLE: CASE VIII DELAVAL ENTERPRISE R-46 450 RPM, 2591 KW 3656 BHP			
SIZE	DRAWING NUMBER	SHEET	REV
A			

FIGURE 1C-15

$$\text{HEAT RATE}_1 = \frac{4200 \times .370 \times 18,799 - \frac{5419 \times 1193 - 5719 \times 127.0 + 3.14 \times 10^6}{.85}}{3030} = 6194 \text{ BTU/KWH}$$

$$\text{HEAT RATE}_2 = \frac{4200 \times .370 \times 18,799 - \frac{5419 \times 1193 - 5719 \times 127.0 + 24 \times 10^6}{.85}}{3030} = 6481 \text{ BTU/KWH}$$

$$\text{FUEL COST}_2 = 6481 \times 2.50 / 10^6 = \$0.01620 / \text{KWH}$$

 THERMO ELECTRON ENGINEERING CORPORATION 85 FIRST AVENUE • WALTHAM, MASS. 02154			
DRAWN	CHECKED	ENGINEER	
P. Gtelo	<i>[Signature]</i>	<i>[Signature]</i>	
TITLE: CASE IX SULZER MODEL: Z40 DIESEL 514 RPM 3030 KW, 4200 BHP			
SIZE	DRAWING NUMBER	SHEET	REV
A			

FIGURE 1C-16

$$\text{HEAT RATE} = \frac{32000(1350.9 - 193.1) + 1609(1208 - 193.1) - 32000(1242.9 - 193.1)}{904 \times .85} = 6623 \text{ BTU/KWH}$$

$$\text{FUEL COST} = \$.0166$$

THERMO ELECTRON ENGINEERING CORPORATION 85 FIRST AVENUE • WALTHAM, MASS. 02154			
DRAWN	CHECKED	ENGINEER	
P. G. eco	<i>[Signature]</i>	<i>[Signature]</i>	
TITLE: CASE 2 A STEAM TURBINE 904 KW NON CONDENSING			
SIZE	DRAWING NUMBER	SHEET	REV
A			

FIGURE 1C-17

$$\text{HEAT RATE} = \frac{16000 \left(\frac{(1350.9 - 193.1) + 804(1208 - 193.1)}{0.85} - 16000 \right) \cdot \frac{(1258.8 - 193.1)}{.85}}{365} = 7380 \text{ BTU/KWH}$$

$$\text{FUEL COST} = 7380 \times \$2.50/10^6 = \$.0185/\text{KWH}$$

THERMO ELECTRON ENGINEERING CORPORATION 85 FIRST AVENUE • WALTHAM, MASS. 02154			
DRAWN	CHECKED	ENGINEER	
P. G. G. C.	J. C. J.	J. C. J.	
TITLE: CASE X B STEAM TURBINE 365 KW NON-CONDENSING			
SIZE	DRAWING NUMBER	SHEET	REV
A			

FIGURE 1C-18

$$\text{HEAT RATE} = \frac{34,000(1350.9-193.1) + 3238(1208-193.1) - 32,000(1242.9-193.1)}{1035 \times .85} = 10,296 \text{ BTU/KWH}$$

$$\text{FUEL COST} = 10,295 \times \$2.50/10^6 = .0257/\text{KWH}$$

THERMO ELECTRON ENGINEERING CORPORATION 85 FIRST AVENUE • WALTHAM, MASS. 02154			
DRAWN	CHECKED	ENGINEER	
P. Gtcco	<i>Yes</i>	<i>Yes</i>	
TITLE: CASE XI A STEAM TURBINE AUTO-EXTRACTION CONDENSING 1035 KW			
SIZE	DRAWING NUMBER	SHEET	REV
A			

 

$$\text{FUEL COST} = \$0.032 / \text{KWH}$$

THERMO ELECTRON ENGINEERING CORPORATION 85 FIRST AVENUE • WALTHAM, MASS. 02154			
DRAWN	CHECKED	ENGINEER	
P. Greco	<i>[Signature]</i>	<i>[Signature]</i>	
TITLE: CASE XI B STEAM TURBINE AUTO-EXTRACTION CONDENSING 935 KW			
SIZE	DRAWING NUMBER	SHEET	REV
A			

FIGURE 1C-20

$$\text{HEAT RATE} = \frac{13.0 \times 10^6 - \frac{5194 \times 1193 - 5394 \times 127.5}{.85}}{800} = 8148 \text{ BTU/KWH}$$

$$\text{FUEL RATE} = \frac{13.0 \times 10^6 \times \$3.00/10^6 - \left[\frac{5194 \times 1193 - 5394 \times 127.5}{.85} \right] \times \$2.50/10^6}{800} = \$0.0285/\text{KWH}$$

THERMO ELECTRON ENGINEERING CORPORATION 85 FIRST AVENUE • WALTHAM, MASS. 02154			
DRAWN	CHECKED	ENGINEER	
P. Greco	WCS	WCS	
TITLE: CASE XII-35-70°F SOLAR - SATURN GAS TURBINE 300 KW (NOM.)			
SIZE	DRAWING NUMBER	SHEET	REV
A			

FIGURE 1C-21

-149-

THERMO ELECTRON ENGINEERING CORPORATION 85 FIRST AVENUE • WALTHAM, MASS. 02154			
DRAWN	CHECKED	ENGINEER	
P. Greco	<i>Yes.</i>	<i>Yes.</i>	
TITLE: CASE XII-90 F SOLAR SATURN GAS TURBINE 800 KW (NOMINAL)			
SIZE	DRAWING NUMBER	SHEET	REV
A			

Table 1C-2
DETAILED COST ANALYSIS, INSIDE JONAS CLARK

A-490

Equipment Costs	2 G-M 870 kW Diesel	1 G-M 2210 kW Diesel	1 G-M 1780 kW Diesel	1 F-M 1530 kW Diesel	2 F-M 850 kW Diesel	2 Sulzer 780 kW Diesels	1 Caterpillar 700 kW Diesel	1 Colt 4550 kW Diesel	1 Enterprise 2591 kW Diesel	1 Sulzer 3030 kW Diesel	1 Non-Condensing 906 kW Turbine(1)	1 Condensing 2000 kW Turbine(1)	2 Solar Gas Turbines
	I	II	III	IV	V	VI	VII	VIII	VIII	IX	X	XI	XII
Engine, Generator & Switchgear	535	400	355	369	644	546	493	1275	1000	1060	285	652	374
Boiler	28	46	38	32	18	29	38	98	58	57	230	310	110
Evolution Boiler	NA	NA	NA	9	10	NA	Note 1	80	NA	31	NA	NA	NA
Cooling Tower	6	8	6	2	2	2	3	7	4	4	NA	41	NA
Cream	16	10	8	10	16	16	10	16	16	16	8	8	10
Water Soft'r & Feed Treatment	6	6	6	6	6	6	6	6	6	6	6	6	6
Building 18 Each	3	4	3	NA	NA	1	NA	NA	2	NA	NA	NA	NA
Tempering 18 Each	3	4	3	NA	NA	1	NA	NA	2	NA	NA	NA	NA
Main Feed Pump	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	15	20	NA
Condensate Pump	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	8	NA
Sub-Total	598	478	420	428	696	601	512	1462	1088	1174	345	1049	501
Freight	30	24	21	21	35	60	16	75	54	59	4	4	13
Total Equipment	628	502	441	449	731	661	528	1537	1142	1233	349	1049	514
Installation Costs													
Civil Work													
Misc Alterations	35	35	35	47	35	35	35	58	47	53	70	81	32
Engine Foundation	17	13	12	14	40	17	20	149	80	80	13	31	17
Boiler Foundation	3	3	3	3	3	3	3	3	3	3	19	3	3
Acoustical	27	27	18	27	27	27	27	24	24	24	24	26	27
Fire-Proofing	12	12	12	5	12	12	12	8	8	8	8	8	1
Chimney	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	46	66	NA
Remove No. 1 Boiler	5	5	5	5	5	5	5	5	5	5	NA	NA	5
Total Civil Work	99	95	94	92	122	99	103	247	167	173	180	209	85
Mechanical & Electrical Work													
Rig in Engine	13	9	7	9	20	5	10	30	20	20	7	7	10
Rig in Boiler	4	5	4	4	4	4	5	5	5	6	15	10	7
Align Engine	2	2	2	2	1	2	2	4	3	4	4	4	2
Install Engine Duct	6	4	4	6	8	6	6	10	10	10	NA	NA	8
Install Boiler Duct	2	5	3	7	8	3	3	8	5	5	24	31	9
Piping, Hangers & Valves	8	24	19	31	19	17	23	45	36	26	42	73	40
Heating Alterations	110	112	110	37	50	110	50	50	108	50	68	68	48
Electrical Work	17	22	18	15	20	16	21	45	29	30	9	9	14
Instrumentation	8	11	9	8	8	7	11	22	14	15	20	20	5
Ventilation	12	12	12	12	12	12	12	12	12	12	16	12	12
Total Mechanical Work	182	206	168	131	182	182	143	231	242	178	205	234	157
Total Equipment	628	502	441	449	731	661	528	1537	1142	1233	349	1049	514
Total Civil Work	99	95	94	92	122	99	103	247	167	173	180	209	85
Total Mechanical Work	182	206	168	131	182	182	143	231	242	178	205	234	157
Total Installed Cost	909	803	723	672	985	942	784	2011	1551	1584	534	1492	756
Engineering Cost at 22%	199	177	159	148	216	207	172	444	341	348	205	324	166
Total Project Cost	1108	980	882	820	1221	1149	956	2455	1892	1932	739	1806	922

Note 1: Included in Engine Price

Note 2: 32,000 lb/hr steam to power. Cost for 16,000 lb/hr noncondensing steam turbine is \$ 978,400.

NA = Not Applicable

Table 1C-3
DETAILED COST ANALYSIS
INSIDE NEW BUILDING

A-488

EQUIPMENT COSTS	Cost in Thousands			
	FM 1530 kW Diesel IV	Pielstock 4550 kW Diesel VII	Sulzer 3030 kW Diesel IX	Condensing Steam Turbine 2000 kW XI
Engine, Generator and Switch Gear	369	1275	1060	652
Boiler	32	98	57	310
Ebullient Boiler	9	60	31	NA
Cooling Tower	2	7	4	41
Crams	10	16	16	8
Water Softener and Feed Treatment	6	6	6	6
Building Heat Exchange	NA	NA	NA	NA
Tempering Heat Exchange	NA	NA	NA	NA
Main Feedpump	NA	NA	NA	20
Condensate Pump	NA	NA	NA	8
Subtotal	428	1462	1174	1045
Freight	21	73	59	4
TOTAL EQUIPMENT	449	1533	1233	1049
Installation Costs				
Civil Work				
New Building	228	258	258	258
Engine Foundation	14	24	20	31
Boiler Foundation	3	3	3	19
Acoustical	NA	NA	NA	NA
Fireproofing	NA	NA	NA	NA
Chimney	NA	NA	NA	NA
Remove No. 1 Boiler	NA	NA	NA	NA
TOTAL CIVIL WORK	245	285	281	308
Mechanical and Electrical Work				
Rig in Engine	9	30	20	7
Rig in Boiler	4	5	6	10
Align Engine	2	4	4	4
Install Engine Duct	6	10	10	NA
Install Boiler Duct	7	8	5	31
Piping, Hangers and Valves	31	45	26	73
Heating Alterations	37	50	50	68
Electrical Work	15	45	30	9
Instrumentation	8	22	15	20
Ventilation	12	12	12	12
TOTAL MECHANICAL WORK	131	231	178	234
Total Equipment	449	1533	1233	1049
Total Civil Work	245	285	281	308
Total Mechanical Work	131	231	178	234
Total Installed Cost	825	2049	1692	1591
Engineering Cost	181	451	372	350
TOTAL PROJECT COST	1006	2500	2064	1941

NA = Not Applicable

- b. The boiler cost is for the bare boiler. For waste heat boilers it is based upon the maximum gas flow from the diesel engine or gas turbine. Waste heat boilers are estimated to cost approximately \$10 per pound per hour of steam generated. Boiler costs for steam turbines are taken from the manufacturer's quotation.
- c. Ebullient boiler costs are assumed to be approximately \$10 per pound per hour of steam generated. The boiler cost for Case VI-B is included in the engine price as a package.
- d. Cooling tower costs for standby on diesel engine jackets are estimated to be \$1200 per million Btu. The cooling tower for Case XI, condensing steam turbine, is from a manufacturer's quotation.
- e. Crane costs take into account the number of engines to be serviced and the weight of the heaviest part to be lifted.
- f. Water softener and feedwater treatment are from a manufacturer's quotation.
- g. The building and tempering heat exchanger costs take account of estimated surface required for the heat load.
- h. Boiler feed and condensate pump costs are from a manufacturer's quotation.

II. Installation Costs

- a. Miscellaneous alterations consist of removal and replacement of inside and outside walls and doors to permit placing the machinery. This cost includes final finish of interior of building and cleanup.
- b. Engine and boiler foundation costs include concrete, hold-down bolts and vibration eliminators. Also included is the cost of excavation and temporary shoring.
- c. Acoustical tile is designed to reduce noise level outside the machinery space to an acceptable level. Cost is based on a material take-off and estimated labor of installation.
- d. Fireproofing is designed to meet regulatory standards for fire protection outside the machinery spaces. Cost is based on a material take-off and estimated labor of installation.

- e. The cost of a new chimney is based on brick construction with an overall height of 95 feet. Included in this cost is breeching through the building wall and cutting necessary cornices.
- f. The cost for rigging in of engines and boilers is based upon a contractor's estimate. All costs from truck to setting in place are included in the price.
- g. The cost for aligning of engines includes all costs to set the engines, including chocking, lineup and final bolting.
- h. Engine ductwork costs include ducting, dampers and expansion joints, and cutting into existing stacks.
Boiler ductwork costs include all breeching from new boiler gas outlet to new or existing stacks, and cutting into the stacks.
- i. Piping, hangers and valve costs pertain to all piping except steam distribution piping necessary to make the boiler steam and return circuits operable.
- j. Process piping is all piping and renovations in the steam and hot water return circuits to and from Jonas Clark and within the Academic Center.
- k. Electrical work includes all motors and controls, and power distribution up to the point of paralleling with the utility.
- l. Instrumentation includes a control panel and all instrument devices required except for electrical controls.
- m. Ventilation is the cost of ventilating machinery spaces.

III. Engineering

Engineering costs represent direct labor of engineering, design purchasing and clerical work required to fully design the demonstration system and make it ready for commercial operation. This cost is customarily a fee plus invoice cost plus mark-up. Also included in engineering costs is field supervision and services of a start-up engineer. Thermo Electron estimates the total engineering cost to be approximately 22% of the total installed costs.

COOPER ENERGY SERVICES

AJAX COOPER-BESSEMER PENN PUMP SUPERIOR

April 29, 1977

Mr. James C. Sullivan
Thermo Electron Corporation
101 First Avenue
Waltham, Massachusetts 02154

Dear Mr. Sullivan:

We have several Model 40 engines, both straight diesel and dual fuel, operating at loads up to 147 bmep and speeds up to 900 RPM with ebullient cooling. The size of engines are 8, 12 and 16 cylinder models, all turbocharged. Any of these engines could be equipped with special injection systems to use residual oil as fuel.

In answer to your specific questions, we are pleased to provide the following information:

1. Our engines can operate from 600 to 900 RPM when burning residual oil. The slower speeds would offer lower maintenance advantage over the 900 RPM configuration but would have the disadvantage of higher initial cost on a per horsepower basis.
2. The engine models which would fit your requirements are as follows:

RATING (KW)	MODEL	SPEED (RPM)	HORSEPOWER
1500	40X16	900	2122
1250	40X16	720	1768
1000	40X16	600	1415
1150	40X12	900	1627
900	40X12	720	1273
750	40X12	600	1061

All of these engines are 10" bore by 10½" stroke turbocharged 4-cycle diesel engines. The above brake horsepower are based on a generator efficiency of 94.8% at all speeds. Obviously this is not an exact number but will place the power ratings in the right ball park.

3. We do not have available complete heat balance data for all of the proposed engines listed above. We have included, however, a couple of representative

Mr. James C. Sullivan
April 29, 1977
Page 2 --

balances which again will place you in the right ball park. Exact heating balance data would not be available until we had an opportunity to operate the engine on the residual fuel with the hardware required.

4. The following design changes would be necessary to make the engine suitable for burning residual oil as fuel:
 - 4.1 Injection pumps would require special clearanced plungers and barrels and have a bypass feature to allow an adequate flow of oil through the pump for cooling purposes.
 - 4.2 The injection nozzles would require special clearances in the area of the valve and seat.
 - 4.3 The injection nozzle tips would require low sac volume and orifice size selected for the particular fuel used.
 - 4.4 The fuel would require pre-treatment including, as a minimum, water washing and centrifuging. Preheating would also be required to reduce the fuel's viscosity in order to make it more easily handled for the treatment necessary. We would be working with commercially available manufacturers of fuel treating equipment to make the final selection. Once the fuel is treated, it would also require additional filtration at the engine. Further heating of the fuel may also be required before and after filtration depending upon the fuel viscosity's characteristics.
 - 4.5 The engine would be equipped with a duplex fuel system which would allow the engine to start and stop on No. 2 diesel fuel and transfer to residual operation after the engine is running.
 - 4.6 Changes in metallic alloys in the fuel system may be required depending upon the amount of corrosives in the residual. My point here is many residuals contain extremely high sulphur and water content which, under the right conditions, can form corrosive acids.
 - 4.7 The use of a high total base number lubricating oil would be required in the crankcase along with more frequent oil change periods. The high TBN oil has essentially high alkaline reserve preventing acid build-up in the crankcase and minimizing corrosion in this area.
5. We would like to have a minimum of one month available for testing an engine with the residual fuel selected. We do have two laboratory diesel

COOPER ENERGY SERVICES
AJAX COOPER-BESSEMER PENN PUMP SUPERIOR

Mr. James C. Sullivan
April 29, 1977
Page 3 --

engines on which this work could be performed providing it doesn't interfere with normal development work underway at the time. If they are available, it would mean we could perform the necessary testing prior to completing the actual engines sold. We would have to work out these details at the time a firm order was in hand.

6. Our standard guarantee would apply which essentially covers defective parts and workmanship. The additional maintenance associated with operating the engines on residual fuel would be the responsibility of the customer.
7. The additional cost associated with the above items would have to be identified by our marketing department. I would presume they would want to make this a part of a formal quotation to cover the specific costs associated with the specific parts involved at the time the quote was made. We have, accordingly, forwarded a copy of this letter to Bill Bicknell, our Industrial Applications Manager.
8. Delivery of the equipment would also be a part of a quotation we would provide. I can tell you, however, the delivery would be dependent upon our production schedule as well as the availability of the major procured items which would be the injection equipment and the fuel treatment systems. My best guess at this time is that these items normally have an availability of six to nine months after receipt of the order.
9. We are enclosing our sales brochure for our Model 40 engines which will describe the engines that will meet your requirements.

We trust this response will sufficiently fulfill your requirements at this time. In the event you require more proposal information, may we suggest you contact our Mr. R. J. Wheelock, 369 Passaic Avenue, Fairfield, New Jersey 07006, Telephone No. 201 227-6730. This is our New Jersey sales office and Dick will be happy to respond to your needs.

Sincerely,

John D. Mowery
Manager of Engineering

JDM/lar
Attachments

cc: Bill Bicknell
R. J. Wheelock - Fairfield, N.J.

COOPER ENERGY SERVICES
AJAX COOPER-BESSEMER PENN PUMP SUPERIOR

HEAT BALANCE

PROPOSAL NO. _____
 REGISTER NO. _____
 CUSTOMER _____

DATE 5/17/76
 ENGINEER JDM

ENGINE MODEL 40-X-12
 ENGINE RATING 1274 BHP @ 720 RPM
 DRIVEN EQUIPMENT 750 KW GENERATOR
 TYPE OF COOLING: ☐ CONVENTIONAL ☒ EBULLIENT
 COOLANT TEMPERATURE (°F) _____
 COOLANT: ☒ WATER ☐ WATER-GLYCOL MIX: _____% WATER _____% GLYCOL
 SEPARATE COOLING CIRCUIT FOR: ☒ TURBOCHARGER
☒ AFTERCOOLER
☒ LUBE OIL COOLER
 FUEL: #2 D LHV = 18190 BTU/LB. DENSITY = 55.4 LB/FT.³

% LOAD
 GENERATOR LOAD (KW)
 GENERATOR EFFICIENCY
 ENGINE BHP
 ENGINE BMEP

50	75	100	110
450	675	900	
0.929	0.942	0.947	
650	961	1274	
72.3	106.3	141.7	

HEAT BALANCE (BTU/MIN.):

POWER
 JACKET WATER
 RECOVERABLE EXHAUST
 LOST EXHAUST
 TURBOCHARGER
 AFTERCOOLER
 LUBE OIL COOLER
 RADIATION & UNACCOUNTED FOR
 TOTAL
 FUEL

27575	40755	54043	
15775	21622	23078	
6359	12729	7071	
10332	12973	14912	
3250	4325	5025	
1300	2330	5025	
4875	6970	6970	
304	1023	11510	
77833	111876	148312	
77833	111876	148312	

HEAT BALANCE (BTU/BHP/MIN.):

POWER
 JACKET WATER
 RECOVERABLE EXHAUST
 LOST EXHAUST
 TURBOCHARGER
 AFTERCOOLER
 LUBE OIL COOLER
 RADIATION & UNACCOUNTED FOR
 FUEL

42.42	42.42	42.42	
23.50	23.50	22.00	
10.55	13.22	16.76	
16.28	12.93	11.70	
5.0	4.5	4.0	
2.0	3.0	4.0	
7.5	7.25	7.0	
12.50	10.55	9.64	
119.75	116.42	117.02	

CALCULATION SHEET HEAT BALANCE

PROPOSAL NO.
REGISTER NO.
CUSTOMER

DATE 8-11-76
ENGINEER SEL

ENGINE MODEL 40 X 16
ENGINE RATING 2115 BHP @ 900 RPM
DRIVEN EQUIPMENT GENERATOR 1500 KW
TYPE OF COOLING: ☐ CONVENTIONAL ☒ EBULLIENT
COOLANT TEMPERATURE (°F) 250
COOLANT: ☒ WATER ☐ WATER-GLYCOL MIX: % WATER % GLYCOL
SEPARATE COOLING CIRCUIT FOR: ☒ TURBOCHARGER
☒ AFTERCOOLER
☒ LUBE OIL COOLER
FUEL: #2 DIESEL LHV = 18190 DENSITY = 55.4 LL/LF 3

% LOAD
GENERATOR LOAD (KW)
GENERATOR EFFICIENCY
ENGINE BHP
ENGINE BMEP

50	75	100	110
750	1125	1500	
.929	.942	.951	
1083	1602	2115	
72.2	106.9	141.1	

HEAT BALANCE (BTU/MIN):

POWER
JACKET WATER
RECOVERABLE EXHAUST
LOST EXHAUST
(1) TURBOCHARGER
(1) AFTERCOOLER
(1) LUBE OIL COOLER
RADIATION & UNACCOUNTED FOR
TOTAL
FUEL

45963	67989	89761	
26534	36045	46530	
18911	29936	43685	
19286	23094	27430	
5415	7209	8460	
2116	4806	8460	
8123	11615	14805	
10893	9624	15515	
137241	190318	254646	
137241	190318	254646	

HEAT BALANCE (BTU/BHP/MIN):

POWER
JACKET WATER
RECOVERABLE EXHAUST
LOST EXHAUST
TURBOCHARGER (1)
AFTERCOOLER (1)
LUBE OIL COOLER (1)
RADIATION & UNACCOUNTED FOR
TOTAL
FUEL

42.44	42.44	42.44	
24.5	22.5	22.0	
17.46	18.69	20.65	
17.79	14.42	12.97	
5.0	4.5	4.0	
2.0	3.0	4.0	
7.5	7.25	7.0	
10.06	6.01	7.34	
126.7	112.8	120.4	
126.7	112.8	120.4	

42.4/7

(1) SEPERATE LOW TEMP H₂O CIRCUIT

SULZER BROS. INC.

Mailing Address:

19 Rector Street
New York, N.Y. 10006

Telephone
Area Code 212
Hanover 5-4560

Cable Address: Sulfra
Telex: 232126

Thermo Electron Corporation
101 First Avenue
Waltham, MA 02154

Attn: Mr. James C. Sullivan

Please quote our reference
in correspondence and
telephone calls

Your Reference

Your letter of

Our reference

Date

7/EJU/ab

May 2, 1977

RE: Jacket Ebullient Cooling for Z 40/48-Engines
Operating on Residual Fuel

Dear Mr. Sullivan:

We thank you for your letter of March 29th on the above subject. In the meantime you will have received Winterthur's telex to your Mr. J. P. Davis which was sent April 22nd, and we would like to confirm as follows:

1. The Z 40/48-engine operating at 515 RPM appears to be capable of operating with a number 6 oil and jacket ebullient cooling with a temperature of 121 degrees without a significant design change. However, the designation: Number 6 oil, is in itself insufficient. It must be further stipulated that the fuel should have a viscosity at 100 degrees F below 3500 sec. Redwood I as well as a vanadium content below 100 PPM and natrium content below 20 PPM.
2. Since the above information is of a preliminary nature, it would be necessary to verify the data given during a 100 hour run in our testbed.
3. If positive results during the above test will be achieved, there will be no change regarding the Sulzer guarantee for such engines when jacket ebullient cooling is applied, if the above mentioned temperature is not exceeded.
4. Since certain modifications to the turbocharger, in particular with regard to the lubricating system (which, however, are already available) would be necessary, a price increase of a few percents must be considered.

./..

To

Thermo Electron Corporation
Attn: Mr. James C. Sullivan

5. Delivery data for such engines would most likely be of the same order as for standard engines.
6. It is very unlikely that smoke readings and emission values would be significantly altered due to the application of the above mentioned ebullient cooling. With the standard engine and a speed of 515 RPM, the exhaust is over the entire load range invisible. Concerning exhaust emissions (measured in grams per BHP/hour), they are as follows: (750 HP/cyl., 560 RPM)

NO_x = 8.80 (All NO_2)

CO = 0.92

HC = 0.50

We hope that the information given will be sufficient for the time being, and please note that the above data is still provisional and should under no circumstances be generalized.

Very truly yours,

SULZER BROS., INC.

by

E. Jung
Technical Mgr., Marine Division

APPENDIX 2A

Environmental Evaluation Report

Appendix 2A

ENVIRONMENTAL EVALUATION REPORT

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May 1977

1. ABSTRACT

It is proposed that a Grid-Connected Integrated Community Energy System (I.C.E.S) be installed at Clark University. The installation will involve the purchase and installation of a 2160 hp diesel engine and generator adjacent to the existing heating plant. This equipment will be linked to the boilers in the heating plant so the "waste" heat from the diesel engine can be utilized in boilers that serve the University's thermal demands. The System would be grid-connected to the electric utility. The utility will purchase excess electricity and sell electricity to the University when its needs exceed its generation capacity. Installation of the ICES will reduce Clark's energy consumption by approximately 25% (52.1 trillion Btu/yr or 362,000 gallons of oil/year).

The Environmental Evaluation Report presents the conclusions of the evaluation of the system's potential impact on the environment, both human and physical. The positive impacts (conservation of scarce resources, net reduction in environmental disruption, maximizing economic efficiency, and establishment of a co-generation demonstration facility) are significant. The findings stated in the preliminary Environmental Impact Assessment and the Massachusetts Environmental Impact Assessment Form indicate that the negative environmental impact will be relatively small. During the evaluation process, the Environmental Impact Group focused particular attention on the proposed system's short and

long range negative effect on the surrounding community, air quality standards, noise levels, and aesthetic situation. In these, as in other areas, the impact of the system, judged according to criteria set by M.E.P.A. and E.P.A., was found to be small.

The proposed ICES system at Clark is a demonstration project and therefore it is necessary to view it in the light of expansion into many similar systems. Indications exist that maybe 10 or 12 institutions or plants in Worcester could benefit from ICES installations. Extrapolating on a state, regional or national basis the number would be very large. In this perspective, the oil savings become a highly significant step towards the national goal of fuel conservation. Some of the small negative environmental impacts of one plant may become significant at the scale referred to above. This is particularly true for NO_x emission if diesel power is the selected generation mode. Expansion of diesel powered ICES could not be uncontrolled in urban areas and may have to be restricted in areas with photo-chemical smog problems.

A further impact of a greatly expanded application of ICES projects would be their effect on the economy of electric utilities. On one hand co-generation may eliminate the need for some expensive system expansion, on the other hand it may distribute fixed cost over a smaller number of customers and reduce output and therefore increase electric rates. Further study of these problems will be needed.

The review process benefitted from a steady interaction between the personnel at Clark University and the appropriate local, state, and Federal regulatory officials. The confidence with which we have determined the project's negative impact to be insignificant is due, in part, to this interaction.

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WALTON, 2020

2. PRELIMINARY

Environmental Impact Assessment

May, 1977

Environmental Impact Assessment (E.I.A.) of the proposed contract EC-77-C-02-4211, "Demonstration of a Grid-Connected Integrated Community Energy System" at Clark University, Worcester, Massachusetts.

Submitted in accordance with the National Environmental Policy Act of 1969 and according to the guidelines promulgated by ERDA on December 8, 1976, and published in the Federal Register, Volume 42, Number 17, January 26, 1977, pp. 4826-4833.

Submitted to: The Energy Research and Development Administration
Chicago Operations Office
9800 South Cass Avenue
Argonne, Illinois 60439

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- III. Description of Existing Environment
- IV. Potential Environmental Impacts
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 - 2. Operation -- long term
- V. Coordination with federal, state, regional and local plans.
- VI. Description of Alternatives
- VII. Conclusion

Submitted by: The Environmental Impact Assessment Group
Professor Harry Schwarz, Coordinator
Clark University
950 Main Street

I. Introduction

The more efficient use of energy is an urgent national challenge. Nowhere is this need greater than in New England where the energy prices and reliance on imported energy supplies are the highest in the country. In response to this situation, Clark University is proposing that it decrease its energy use through the installation of a co-generation system. This system would involve the generation of electricity on campus by a diesel generator and the utilization of the engine's "waste heat" in the University's steam heating system. By utilizing the heat that is normally lost in the generation process, the energy efficiency of the co-generating system will be approximately 25% higher than at present.

Similar co-generation systems have a proven record of safety, technologic success, energy conservation, and economic savings in many European countries.

II. Description of the Proposed Action

The co-generation system would involve the installation of a Fairbanks-Morse 9 cylinder, 38TD diesel rated at 2160 Bhp at 720 RPM. The diesel would generate 1530 kilowatts of electricity and provide 4.16×10^6 Btu/hr of energy to the University heating plant. When in operation the system will meet the University's entire electrical demand. The system will be integrated with Massachusetts Electric Company. The utility has agreed to purchase electricity generated in excess of the University's demand and to sell electricity to the University when the

generator is not in operation or otherwise unable to fulfill the University's demand. The thermal load of the University that exceeds the diesel's output will be provided by the present boiler system.

The positive environmental impacts include: (a) the conservation of scarce resources, (b) maintenance of the financial strength of Clark University, (c) the creation of an energy conservation demonstration facility in Massachusetts, (d) enhancement of Clark University's programs and reputation in energy management, (e) additional experience in the design, construction and operation of co-generation facilities by the technical participants, (f) the expenditure of approximately one million dollars in some of the most economically depressed regions of the country, (g) a reduction in the emission of some air pollutants, (h) reduction in the negative environmental impacts involved with the extraction, processing and transport of fuels, and (i) decreasing the negative economic impacts that result from New England's dependency on expensive imported oil, (j) assisting in a more positive national balance of payments, and (k) reducing the political vulnerability that results from the nation's lack of energy self-sufficiency.

The anticipated negative environmental impacts may be associated with the construction (approximately 6 months) or the operations phase. The former include (a) additional traffic on the campus, (b) the aesthetic impact (audio and visual) of the construction operation, (c) emission of particulate matter (dust) in the local area. Anticipated negative impacts of the

operational phase include: (a) an increased emission of some air pollutants, (b) the noise and vibration of the diesel engine and generator, (c) the increased presence of oil delivery trucks, (d) the visual and physical impact of the building that will house the diesel and generator, (e) the audio and visual impact of the system's small cooling tower, and (f) an element of unknown risk that accompanies the alteration of an existing system. All of these impacts, including an evaluation of the significance of each, are discussed in detail in Section IV.

III. Description of the Existing Environment

For the purpose of evaluating the system's environmental impact, the description of the existing environment has been divided into five categories: (a) the present energy system, (b) the existing building that the system will be located in, (c) the University campus, (d) the surrounding residential community, and (e) metropolitan Worcester.

(a) The Present Energy System. The central heating plant is located in the northwest quadrant of the basement of Jonas Clark Hall (see Map EIA-1). There are three boilers - two rated at 21×10^6 Btu per hour and one rated at 29×10^6 Btu per hour. The peak thermal demand of the University can be met by one of the small and the larger boiler. The steam and hot water are piped through a network of underground tunnels to the other buildings on campus (see Map EIA-2). The boilers can be adapted to burn either residual (#6) or distillate (#2) oil, or natural gas. Exhaust from the boilers is vented through a 95 foot

EIA Map 1.

Plan of the East wing of Jonas Clark Hall, showing the present boiler plant and the space for a possible grid-connected ICES.

EIA Map 2

— 125 psig steam lines
 — 40 psig steam lines
 — 15 psig steam lines

Steam distribution system at Clark University. Steam lines in all cases include both steam supply and condensate return.

1. Downing Administration Center	18. General Store/Birth Control Center
2. Atwood Hall	19. Wright Hall
3. Academic Center	20. Little Center for the Visual and Performing Arts
4. Geography Building	21. Dodd Hall
5. Jefferson Hall	22. Johnson Hall
6. Alumni Gymnasium	23. Sanford Hall
7. Science (Bio-Physics) Building	24. Estabrook Hall
8. Jeppson Laboratory	25. Physical Plant
9. Jonas Clark Hall	26. Alumni House
10. Robert Hutchings Goddard Library	27. English House
11. Bullock Hall	28. Carriage House
12. Potter Laboratory	29. Department of Management
13. Dana Commons	30. Nursery School/Commuter Lounge
14. Dana Dormitory	31. Downing Residence
15. Hughes Hall	• Restrooms and Public Telephone
16. Florence Residence	P Parking Area
17. Student Activities Center	

stack mounted on the north side of the building. The oil is delivered on campus by tanker truck and stored underground in two 20,000 gallon tanks. The boiler operations are inspected periodically and meet all local, state, and federal regulations. They are operated by specially licensed personnel.

Electric power is supplied by Massachusetts Electric Company, a member of the New England Electric System. The electricity is provided by a single, 13,800 volt utility line. It is connected to University owned transformers located on the North side of Jonas Clark Hall near the heating plant. Electricity is distributed from this point throughout the campus.

(b) Jonas Clark Hall. Jonas Clark Hall is located in the center of the campus (see Map EIA-2). It was built in 1887, is a brick construction, has four floors and contains 84,289 gross square footage. As mentioned previously, the present boiler system is located in the northwest corner of the building's basement. An old gym, craftshop, gameroom, three small laboratories, and a lavatory are also located in the basement level. The three upper floors are devoted to classrooms, faculty offices, and the offices of the College of Professional and Continuing Education.

Although the sound levels inside the boiler room are high (95-85 decibels), the building's thick brick walls, the boiler room's brick ceiling, and sound proofing reduce the sound levels immediately outside the boiler room to the ambient level. (See Table EIA-1 for specific decibel readings.) The sound reduction is important since the building is set in the center of the campus.

Table EIA - 1

Noise levels at Clark University^a

Location	Noise level (dB)
Main Street, heavy trucks	95
Inside present boiler plant	95
Main Street, normal traffic	75
Outside window of present boiler room	70
Residential street at back of campus	70
Inside Clark computer center	68
Inside room with people talking	65
Street enclosed by campus, no cars	55
Park across Main Street, opposite Clark	55
Dormitory quadrangle	52

- a. Data measured by students in the Program on Science, Technology and Society with a portable dB meter.

(c) The Campus. The University owns 35 acres of land. The area covered by the main buildings and served by the central steam distribution system is 15 acres. The University owns 46 buildings, of which 21 are considered "major." There is approximately 1,000,000 gross square feet of building space. (Map EIA-2 indicates the layout of the central campus.)

The architectural styles of the buildings vary considerably, representing a history of the changing perceptions of the "academic style" held by architects and administrators. The result is a combination of modified gothic, New England mill, high efficiency barracks, and modern irregular. A 12 person aesthetics committee advises on architectural changes that might detract from or intrude upon this architectural melange.

Clark is a small university with about 2,000 undergraduates, 250 graduate students, 280 staff members and 140 full-time faculty members. This results in a campus week day population of 2,600 and an evening/weekend population of 1,200 when the University is in session. Clark has not escaped the recent economic pressures familiar to private universities. Tuition raises have been a regular, unavoidable feature as have staff reductions and very modest salary increases for the remaining staff and faculty. In the 10 year period from 1965 to 1975, the University's total energy costs rose from \$81,000 to \$560,000. The University's energy costs in 1976 were \$389,938, which indicates that Clark's efforts to respond to these pressures have been determined and effective. Past operating deficits have been eliminated, active cost cutting measures have been under-

taken, a major fund raising campaign is underway, energy conservation efforts have reduced thermal demand by 41% between 1972 and 1976 and electrical demand by 41% between 1970 and 1976, and imaginative programs have been instituted to both attract superior students and insure the financial stability of the University. The proposed co-generation system is, of course, one such project. (See EIA Figure 1)

(d) The Community. The University's campus is situated in a residential neighborhood 1.2 miles south of the city center (see Map EIA-3). The campus is set in a high density landscape typical of urban New England. On three sides the neighborhood consists of two and three story houses (triple deckers) located on small, narrow lots. Some of these structures are single family residences, but most contain several rental units. The median family income of the area was \$8,819 in 1975. Main Street lies to the east of the campus. It is a major artery and truck route. On it are located a number of small service oriented businesses, churches, and public service organizations. The residential neighborhood resumes to the east of the artery (see Map EIA-3).

The University's relations with the surrounding community are generally positive. The primary issues of community-university conflict are all related, but for clarity are presented separately here. (1) There has been a serious lack of student parking on campus. Although the university added 140 new parking spaces in 1976 and will add 200 spaces in 1977, the problem is still not entirely resolved. (2) Students rent many of the apartments in the area surrounding the campus. Some residents

ELA Figure 1.

Illustration of energy consumption at Clark
since 1970.

in the community feel that this movement has decreased the community's viability. (3) The issue that has caused the most stress is the University's purchase of adjacent, residential property for expansion. Similar to student apartment renting, the same residents feel that this decreases the number of school age children in the community and jeopardizes the continued operation of the community elementary school on Downing St. Since the University plans no major future expansion, this dispute should not be an issue in the future. A significant aspect of the proposed ICES installation is that it will not affect any of these areas of University-Community conflict.

(e) Metropolitan Worcester. The city of Worcester has a population of approximately 170,000 and more than 6 million people live within 50 miles of the city. Although Worcester is the second largest city in New England, it is best described as an old, medium-sized, industrial city. Similar to many cities in the Northeast, the post World War II era has brought changes that have stressed the economic and social fabric of the city. The population has declined as the more affluent moved to the suburbs, textile and related industries have closed, the tax rate has continuously increased, urban renewal programs have met with only partial success, abandoned buildings degrade older neighborhoods, etc. Recently the city's response to these problems has been more effective and actually reversed many of the negative trends. The city center is being revitalized, and the exodus of people and industry has slowed, newer service industries are expanding.

Clark is one of eleven colleges and universities of the Worcester Consortium of Higher Education. These institutions combine to become one of the largest employers in the city. For this and other reasons, the well-being of the region's colleges and universities is critically important to the resurgence mentioned above.

Worcester, like the rest of the Northeast, suffers from extremely high energy costs. These costs exceed those in any other part of the country. Most industries and many individuals have instituted conservation measures and reduced their energy consumption significantly. But further conservation measures, such as Clark's ICES proposal, will be necessary if the city and region are to remain economically competitive in the future.

The most persistent, specific "environmental" problem in Worcester is the high particulate content of its air. Worcester is presently a "Non-Attainment" area for particulate matter, consistently violating the state air quality standards for particulate matter.

A review of the quarterly air pollution measurements at Clark, contained in EIA Table 2, indicates that the particulate levels exceed the standards by a maximum of 25% over the past 5 years.

ElA Table 2

Quarterly air pollution at Clark^a

Year	Total suspended particulates ^b (ugm/m ³)				SO ₂ ^c (ppb)				NO ₂ ^d (ppb)			
	1	2	3	4	1	2	3	4	1	2	3	4
1971			62	68			9	14			78	71
1972	76	62	50	46	13	6	4	14	42	34	42	39
1973	76	44	43	55	15	3	1	6	29	47	51	24
1974	68	62	40	51	12	2	1	13	30	25	21	32
1975	63	58	32	40	16	4	4	12	30	24	19	36
1976	57				11				29			

a. Data supplied by Edward Benoit, District Chief, Central Massachusetts Air Quality Control District. The numbers quoted are quarterly mean values.

b. Federal and Massachusetts Air Quality Standards for Total Suspended Particulates are.

	<u>Primary</u>	<u>Secondary</u> (in ugm/m ³)
Year	75	60
Day	260	150

c. SO₂ levels at Clark are less than 1/3 of typical values encountered in major cities.

d. NO₂ levels at Clark are 1/3 to 1.2 of typical values encountered in major cities.

The high particulate content of the air is thought to be a result of the topography of the city. The city is extremely hilly and this results in the use of excessive amounts of road sand in winter. In addition, the city is located in a basin

which discourages dispersion of particulates and encourages the development of temperature inversions.

IV. Potential Environmental Impacts

A. Positive. The positive impacts that were listed in section II will be discussed in detail in this section.

The conservation of scarce resources is one of the primary objectives of the installation. Measures that result in significant reductions in national oil consumption without serious economic or environmental disruption must be viewed as positive contributions to the human and physical environment. The significance of these actions is even higher when it occurs in regions which have no indigenous sources of fossil fuels. The ICES plant will reduce Clark University's total energy consumption from 213.3×10^9 Btu to 161.2×10^9 Btu per year or by approximately 25%. These figures correspond to a reduction of 362,000 gallons of oil consumed per year to meet the University's electrical and thermal needs. The total energy savings are even greater in terms of net energy savings due to energy saved by not needing to extract, transport, and refine the 362,000 gallons of oil per year.

In the context of fuel conservation, the ICES installation should be viewed as part of the University's overall commitment to reduce its energy consumption. This commitment has been active and effective. Since 1970, the University has managed to reduce its thermal energy demand by 41% and its electrical demand by 41%. These savings have been achieved through the

efforts of students, staff and faculty, energy use studies, the improved efficiency of end use equipment, an IBM System load dropping computer and improved thermostatic and electrical controls.

The maintenance of the financial strength of the University is a significant attribute of the ICES proposal. The cost of fulfilling the energy requirements at Clark in 1975 was \$560,000. This amounts to approximately 20% of the amount spent on faculty salaries at the University. Reducing these figures by 25% would be a very positive economic impact. Since other conservation measures have already been successfully implemented, the ICES installation is the only practical means of further reducing the University's energy cost burden.

Clark is a private university and tuition costs have increased dramatically over the last decade. Already many individuals are excluded from attending for financial reasons. The savings from the ICES will help to reduce further tuition increases, maintain the University's ability to compete for the most qualified students, and hopefully, renew opportunities that were previously closed due to high tuition rates. It should be pointed out that presently Clark benefits from a declining block rate pricing structure. The projected savings of the ICES will be larger if these rates move towards a more uniform rate structure.

The creation of an energy conservation demonstration facility in Massachusetts would be a positive contribution of the ICES installation. Establishment of a co-generation demon-

stration plant, of a size and scale appropriate to many industrial, commercial, institutional, and public facilities would be an important asset to the region. The effect that the ICES would have as a demonstration site encouraging similar conservation efforts by others is the primary reason the project has received the attention and support of the Commonwealth's Governor and Energy Policy Office.

Three factors insure that the ICES installation will provide an effective demonstration facility. First, Worcester is unusually accessible to the rest of New England. The city's motto "The Heart of New England" implies and its location on I-90 and I-290, functioning train station and airport insure ease of access to the facility. Over 50% of the region's population lives within 50 miles of the Clark Campus. Secondly, the University has established an impressive record in monitoring and recording its energy use patterns. The Science, Technology and Society Program at Clark has devoted three issues of its journal to energy use at the University. Finally, the demonstration facility would include information on the University's other conservation efforts which, as noted above, have been extremely effective.

The ICES will enhance Clark University's programs and reputation in energy management. Clark has become a center for a considerable amount of research in the energy field. This research has ranged from projects in methane gas digestion, solar energy, wind energy, conservation technologies to funded research in the societal risk of nuclear power, the electric utility-solar energy interface, and methane gas generation from waste treatment

plants. Students and faculty in two departments, Geography and Physics, and two Programs, Environmental Affairs and Science, Technology, and Society, have been particularly active in the field of energy research. A co-generation facility on campus would provide numerous new research opportunities. Installation of an ICES system at the University would enhance the University's position in the energy management field.

The ICES installation will result in additional experience in the design, construction and operation of co-generation facilities by the technical participants. Although the concept of co-generation has been understood for many years and many such facilities exist in Europe, there is relatively little technical experience with them in the United States. Installation of the ICES plant at Clark should be considered an important addition to this experience. This experience is an important addition to the technical resources that the nation will need to respond to the energy crisis. Since this installation will play a significant role in moving co-generation from theoretical concept to political reality, the increase in the knowledge gained in dealing with the issues involved in each step (design, construction, and operation) is a very positive impact resulting from the ICES.

The expenditure of approximately one million dollars in some of the most economically depressed regions of the country. The ICES installation will involve the dispersal of about one million dollars in the national economy. The money will help generate jobs in the regions where unemployment has been most

persistent and severe -- New England and the Upper Mid-West. In New England many of the jobs will be in the construction field where unemployment levels have been especially high. If the Clark University ICES acts as a stimulus for other installations (as is expected), the positive effect on regional employment levels would be even more significant.

A reduction in the emission of some air pollutants will occur because the increased efficiency of the ICES will result in reducing total oil consumption by 362,000 gallons. The savings will be at the Massachusetts Electric generating stations. Assuming that the fuel not consumed is residual oil, the emission of particulate matter will be reduced by 1.2 tons/year and SO₂ emissions will be reduced by 55.2 tons/year. (See EIA Table 3)

Reduction in the negative environmental impacts involved with the extraction, processing and transport of fuels. The 362,000 gallons of oil that is conserved by the ICES installation also contributes to the reduction of the negative effects often associated with drilling, refining and transportation of oil. This positive impact is not very significant, but it is a factor that should be considered when evaluating the decisions that may encourage or discourage the widescale use of ICES.

Decreasing the negative economic impacts that result from New England's dependency on expensive imported oil. New England's dependency on more expensive, foreign oil supplies contributes to the region's high cost of living and higher operating costs for business establishments. Electricity rates in the region are

particularly high and act to discourage the growth of industries that use large quantities of that source of energy. In addition, the region is particularly vulnerable to actions that reduce the availability of oil shipments. Installations of the ICES would reduce the region's dependence on foreign supplies and vulnerability to another embargo. As such, it would improve the economic potential of the region significantly.

Assisting in a more favorable balance of trade. Since the rapid rise in oil prices in 1973, oil imports have consistently been the most expensive item imported by the United States. With oil imports now exceeding domestic production, the ability of the nation to maintain a surplus balance of trade will be severely tested. Installation of the ICES system will decrease the outflow of money. Presently, approximately 75% of New England's residual oil is from foreign sources charging \$12.00 a barrel. At these rates, the ICES would save \$82,000 per year, a small amount when compared to the billion dollar trade figures, but still a savings.

The political vulnerability that results from the nation's lack of energy self-sufficiency. As stated in the proposed National Energy Plan, complete energy independence is an unrealistic goal. Nevertheless, programs that reduce the nation's need to import foreign supplies of oil and gas do reduce the influence that fossil fuels have on the political decision-making process. The fuel conservation of the ICES installation will contribute positively to the nation's political environment.

IV. B. The Negative Environmental Impacts

The potential negative environmental impacts of the construction and operation of the ICES were listed in Section II. They are discussed below in greater detail.

Construction Phase. The negative impacts of this phase are like those associated with similar construction projects. The length of the construction phase is difficult to estimate at this point in time, but it is probably about 6 months long. The negative impacts that will be experienced in this phase include:

Additional traffic along Downing Street and at the site on the north side of Jonas Clark Hall. Since Downing Street is near and Jonas Clark Hall is at the center of the campus this will have a disruptive effect. The inconvenience of heavy machinery on the compact campus will be greatest when the excavation equipment, dump trucks, and cement trucks are on campus.

The aesthetic impacts, both audio and visual, will persist throughout the construction phase. This impact should not be too great since the installation is not a large construction project, yet it is located in the center of the campus. Clearly, it will be necessary to insure that the most disruptive aspects of the construction phase be conducted when the University is not in session.

Particulate emissions, primarily dust, will be generated during the production process. Although these emissions will not be significant, they are mentioned here because of Worcester's air particulate problem.

In summary, the negative environmental impacts of the construction phase are mainly related to inconvenience. To keep this inconvenience to a minimum, it is important that the construction be undertaken during the late spring and summer months when the University is not in session.

B. The Operations Phase. The negative environmental impacts of the operations phase are considered to be more important than those of the construction phase because that phase will be relatively brief. The negative impacts of the operations phase include:

An increased emission of some air pollutants. While the ICES will reduce the emission of some emissions, NO_x emissions will increase by approximately 106.7 tons, CO will increase by 18.5 tons and HC will increase by 6.3 tons. The air quality impact is more negative if only the Worcester region is considered (instead of the New England region which includes the Massachusetts Electric generating plants). Clark's impact on the local air quality is listed in Table EIA-3.

Worcester is a "Non-Attainment" area for particulate matter at the present time. In the local area, emissions in this category will be increased by 1.4 tons. This figure is relatively low. The NO_x emissions do represent a major increase both at Clark and in the New England region. However, levels of NO_x in the Worcester region are well below the ambient standards and there is no photo-chemical smog problem in the region. It should be noted that the Regulations as Amended for the Control of Air Pollution exempt diesel engines from NO_x limits. In addition NO_x is a dispersing pollutant, so higher emissions will not result in

EIA Table 3

Estimated Air Pollution Impact - Present System and Proposed
Grid Connected ICES

System	Annual Emission (in Tons/Year)				
	SO ₂	NO _x	CO	HC	Particulates
Present System					
Utility boiler ^a	36.2	25.2	--	0.47	1.5
Clark boiler ^b	76.9	53.4	--	1.0	3.2
System impact ^c	113.1	78.6	--	1.47	4.7
ICES System					
Clark Diesel ^d	30.7	166.0	18.5	7.4	2.3
Clark boiler	54.0	37.8	--	0.7	2.3
Utility boiler	-26.8	-18.5	--	-0.35	-1.1
System impact	57.9	185.3	18.5	7.75	3.5
Net Change					
At Clark	+ 7.7	+150.4	+18.5	+7.1	+1.4
% Change ^e	+10%	+280%	NA	+700%	+43%
Auto equivalents ^f	-	3000	34	101	--
New England ^g	-55.2	+106%	+18.5	+6.3	-1.2
% Change	-49%	+135%	NA	+450%	-26%
Auto equivalents	-	2140	34	90	--

- a. Based on generalized data for utility boilers burning residual oil with an ash content of 0.04% (by weight), sulphur content of 1.0% (by weight), weight of 7.83 lbs per gallon, 148,000 btu per gallon and a btu to kwh ratio of 10,050 to 1. Assuming the consumption of 6.8×10^6 kwh per hear.
- b. Based on the use of residual oil with the same characteristics as specified in note a and a boiler efficiency of 75%. Assuming a thermal load of 109×10^9 btu per year.
- c. Carbon monoxide levels (less than .01 tons) are considered negligible here.
- d. Based on the manufacturer's specifications and the use of distillate oil with an ash content of 0.02% (by weight), sulphur of 0.50% (by weight), a weight of 7.70 lbs per gallon, and an energy value of 140,000 btu per gallon. Assuming operation at full capacity for 7750 hours per year.
- e. The percent change for carbon monoxide is meaningless since basically none was emitted previously.
- f. Auto equivalents are included to provide a means of evaluating the relative significance of the net changes. They are based on EPA's estimates for the average emissions of all the motor vehicles operating in the U.S. in 1976.

- g. The New England figures represent the net additional emissions of the Clark ICES and net reduction in the emissions at New England Electric System's residual oil fired generators. Assumes a net reduction in NEES's oil consumption by 397,000 gallons per year.

Additional data and assumptions that relate to the air quality impact are contained in Section 4 of this Appendix.

significantly higher concentrations at the site. As a result of these factors, the NO_x emissions do not appear to result in a significant negative impact in the opinion of the EIA team and the Director of the Central Massachusetts Air Quality Control District. However, these emissions will be critically reviewed in the Air Quality Analysis at a later stage in the design process.

Noise and vibration of the diesel engine and generator.

These impacts are potentially significant but can and will be eliminated through proper design and construction techniques. To insure that vibration is kept to a minimum, the diesel and generator will "float" on a cement pad independent from Jonas Clark Hall. Sound proofing will be applied to insure that the ICES will meet the noise standards as specified by the Commonwealth and approved by the EPA. Noise levels at other co-generation installations indicate that noise reduction should not be a difficult process. Commonwealth Gas Corporation's co-generation plant in Southborough, Mass. reduces the noise levels from 95-104dB in the generator room to 61-66dB in the observation room with standard construction techniques.

The increased presence of oil delivery trucks will result from the increase of 492,900 gallons of fuel consumed on the Clark Campus. At present there are approximately 123 deliveries per year. The ICES installation will require about 60 additional deliveries per year. This represents an increase of nearly 50%. Aside from their visual and olfactory impact, the increased presence of 8000 gallon fuel trucks carries with it an element of

risk. The increased presence of these trucks is only considered significant on the Clark Campus and Downing Street. Other streets, such as Main Street, are major truck arteries and 60 more trucks per year will be insignificant.

The visual and physical impact of the ICES building. Pending analysis, two locations are being considered for the ICES. The system may be installed in one of the biologic laboratories in the basement of Jonas Clark Hall (see EIA map 1) or in a separate building on the north side of Jonas Clark Hall. The former location will not be visible from the exterior of the building but will reduce classroom space. The exterior location will require an addition of about 40 by 60 feet. This building will have an effect on the appearance of Jonas Clark Hall which is a focal point of the campus. The University Aesthetics Committee will review these proposals before a final decision is reached. The exterior location will also intrude upon the campus that already is lacking in "green space." However, the outside location reduces the levels of unknown risk that is involved with installing the system within the 90 year old building.

The audio and visual impact of the cooling tower may produce negative impacts. A more definite evaluation will be presented after the exact sizing and location of the cooling tower is determined.

Elements of unknown risk accompany any alteration of an existing system. To reduce potential of this negative impact becoming significant, the ICES system will use only proven equip-

ment and engineering techniques. The experience of the technical partners in co-generation should reduce this threat still further.

In summary, the known negative impacts from the ICES are not deemed significant. It should be noted that the ICES system's negative impacts are relatively contained within the Clark University campus. As a result, almost all of the negative impacts are experienced by the same people who benefit from the more significant positive impacts. Negative impacts on third parties, such as the local community, are minimal.

V. Coordination with Federal, State, Regional and Local Plans.

The ICES installation is only feasible if it can comply with all of the appropriate statutes, codes and regulations. The importance of complying with these legal and institutional factors has been recognized throughout the planning process. Aside from these specific factors, it is also important that the ICES not conflict with any policies and programs of Federal, state and local governments. The relevant items and the steps that have been undertaken in response to them are discussed below. The specific codes and letters from appropriate regulatory and planning officials are contained in Appendices 2B and 2C.

Environmental Impact Analysis. Regulations regarding overall environmental impact analysis are presented in Chapter III, U. S. Energy Research and Development Administration, Part 711 - Guidelines for Environmental Review published in the Federal Register, 26 January 1977, pp 4826-4833. (See Appendix 2B). These regulations require that an Environmental Impact Assessment (EIA) be

written as specified in Part 711 - 25 of the regulations. This document is a preliminary draft of an EIA based on the present state of knowledge on the Clark ICES installation. This report will be updated and expanded as the planning process continues.

The applicability of the state requirements for an environmental impact assessment is unknown at the present time and will depend on the degree of involvement of the Commonwealth in the ICES project. A preliminary draft of a Massachusetts Environmental Assessment Form is included as section 3 of this report. It was completed in accordance with specifications contained in "Preparation of Environmental Impact Reports" (see Appendix 2B).

Air quality standards. The exhaust emissions of the ICES installation are subject to state and Federal air quality standards. The main applicable regulations are the Federal and Massachusetts Air Quality Standards (40 CFR 50), Requirements for Preparation, Adoption, and Submittal of Implementation plans (40 CFR 51), Interpretive Ruling for Implementation of the Requirements of 40 CFR 51.18, and Regulations as Amended for the Control of Air Pollution, Dept. of Environmental Quality Engineering, the Commonwealth of Massachusetts as amended through 13 June 1975. (All of the above regulations are contained in Appendix 2B).

Emissions figures have been reviewed by Mr. Edmond G. Benoit, Chief, Central Massachusetts Air Quality Control District. Mr. Benoit has stated that, based on presently available data and pending more detailed analysis, the project would not be in

violation of air pollution regulations (See letter in Appendix 2C). Moreover, Mr. Benoit is very supportive of the project and its ability to provide better data as to the air quality impact of co-generation systems. The staff of the Central Massachusetts Air Quality Control District will be asked to recommend the most appropriate monitoring equipment to gather this data.

Further discussions have been held with air quality specialists at EPA's Region I, Boston office. They confirmed that compliance with all state standards will also guarantee compliance with Federal regulations.

Noise regulations. The Director of the Central Massachusetts Air Quality Control Board has jurisdiction over noise pollution under the Regulations as Amended for the Control of Air Pollution, Dept. of Environmental Quality Engineering, Commonwealth of Massachusetts, adopted 26 Jan. 1972 and amended through 13 June 1975. (See Appendix 2B). He foresees no difficulty in meeting these standards. Representative of the EPA noise pollution branch in Boston also have been contacted. They stated that the Commonwealth's standards either meet or exceeded theirs and would be acceptable.

Building Codes. The applicable building codes are contained in Article II, "Heating Equipment and Appliance mounting, Clearances and Connections." of the State Building Code. In addition, boilers and unfired pressure vessels are subject to the provisions of Chapter 146 of the MGLA as amended. These issues

have been reviewed with Mr. Norton Remmer, Commissioner, Dept. of Building Code Inspection of the City of Worcester. Commissioner Remmer states that compliance with all requirements of the building code can be achieved by applications of standard designs and construction techniques. (See letter in Appendix 2C.) The provisions of Chapter 146 require the approval of certain boilers and pressure vessels by the Board of Boiler Rules of the State Department of Public Safety. Such approval will be obtained, if appropriate, once detailed designs and specifications are known.

Zoning. The City of Worcester Zoning Ordinance applies to the University and the ICES installation. Clark is located in a residential district which is permissible under Section 15A (6) of the code (See Appendix 2B). The ICES installation was discussed with Mr. Remmer, Commissioner, Dept. of Building Code Inspection, City of Worcester. He stated that the project would not violate existing zoning regulations (See letter in Appendix 2C). The Office of Community Planning and Development was also contacted to insure that the installation did not interfere with the plans and programs of that agency. They indicated that the project would not affect their plans. The Worcester Redevelopment Authority, an agency that operates in the vicinity of the Clark campus, has also indicated that they have no objection to the ICES installation (See letter in Appendix 2C).

To conclude, the Clark ICES proposal does not conflict in a significant manner with any specific legal and institutional requirements or the plans and policies of related governmental

agencies. On the contrary, the majority of these entities supported the ICES proposal on the basis of the positive impacts such a system would have on energy conservation and economic welfare of the community. The advice of the regulatory personnel have been of great assistance to the Environmental Impact Assessment Group. The Group will continue to seek their advice and opinions in the future.

VI Description of Alternatives.

There are four sets of alternatives open to Clark University. Those being: (1) to continue with present practices; (2) to institute additional strong conservation measures to reduce energy demand; (3) to install a totally independent integrated energy system; or (4) to select a different grid connected ICES system.

Continue with present practices.

This alternative would have no environmental impacts at Clark University, it would however continue unabated use of oil within the New England area. This would, therefore, be contrary to the national and regional objective of fuel conservation. Furthermore, it would continue Clark's vulnerability to cost increases in fuel and electricity with the inherent danger to its financial stability and the indirect effect of financial instability on the student body, the faculty and the community.

Institute additional conservation measures.

The University has already instituted strong conservation measures. The principle one being an IBM System 7 load dropping

computer which has 26 electric controls and 13 steam controls. The computer is programmed to balance loads, essentially reducing peak demand. The introduction of this conservation device in conjunction with simpler conservation rules has already resulted in a reduction of about 35% for the thermal load and 45% of the electric load. Investigation of further conservation measures indicate that such measures are likely to produce adverse effects on the Clark community, produce increasingly marginal conservation yields and as a corrolary, increases in marginal costs. Fuel savings would be only proportional to energy input reduction with no improvement in fuel to energy conversion efficiency.

Independent integrated energy system

Total energy plants for the Clark campus not connected with the existing electric grid have been investigated in several studies. Such systems have generally the same advantages as a grid connected ICES. Cost, however, are higher as system's reliability must be achieved by the installation of standby units. Engineering studies show that the cost of interconnection including standby charges for electricity are lower than those of standby units.

Different grid connected ICES

A large number of alternative ICES installations including differently sized diesel units, steam turbines and gas turbines were investigated. These investigations showed that diesel units produced the best balance between efficiency and tech-

nologic risk, that generally larger units produced increased efficiency and rate of return and also higher initial cost. On environmental grounds few differences can be ascertained except that larger units are likely to increase aesthetic problems, air pollution but reduce oil consumption. On economic grounds, larger units in addition to increased initial cost, represent higher opportunity cost and larger risks.

VII Conclusion

Based on the previous section of this environmental assessment, the following conclusions can be derived.

- (1) There will be no significant negative or positive environmental impacts at the project site, i.e. the Clark campus. Physical changes will be minimal and do not affect ecologically sensitive areas. Aesthetic effects and noise effects can be mitigated by proper facilities design. Air pollution effects at site will be minimal as the increase in pollutants that have localized effects such as CO, SO₂ and particulates is small.
- (2) Socio-economic effects at the project site are beneficial. Significant financial savings accrue to Clark University and the presence of the demonstration project will enhance the reputation and academic programs of the University.
- (3) Community environmental effects of the project are negative, however, only to a small degree. The significant output of NO_x will increase the NO_x level in Worcester. This however is not serious as the present ambient NO_x level is well below ambient

standards and there are no local photo chemical smog problems. Traffic in the area surrounding Clark will be increased slightly by the increased frequency of oil delivery trucks and there may be some temporary nuisance conditions during construction.

(4) Socio-economic effects on the community are expected to be small but positive. The increased local expenditure for construction, operation and maintenance should to some degree enhance the community.

(5) Regional environmental impacts of the project are small on a national scale but they are positive and as a demonstration project, this is highly significant. Oil savings of nearly 8000 barrels per year may not be large when compared with the present national consumption of that fuel, but being nearly 25% of the fuel consumed for Clark's need, they are a significant indication of the contribution that grid connected ICES can make towards the national goal.

(6) Regional and national socio-economic impacts, while insignificant by themselves, are important as indicators of the opportunities that exist, through cooperation of individual institutions, utilities and government towards achievement of socio-economic goals.

(7) The overall increase in the emission of nitrogen oxides, carbon monoxide and hydrocarbon indicate that the increased efficiencies of co-generation systems are not without environmental cost. The increases from a single ICES at Clark are not

considered significant. However, it is important to project the impact of many such installations to gain a more thorough understanding of the total environmental impact. As a demonstration project, the Clark ICES will provide more precise data to anticipate these impacts. At present, the figures suggest that large numbers of diesel powered ICES should not be installed in regions with high NO_x concentrations or high incidence of photochemical smog without careful evaluation of their impact.

**Please read Environmental Assessment Form Manual
before filling out this form.**

Enter Code

Enter Publication Date:

Address: _____

9. Summary of Proposal (narrative):

The co-generation system would involve the installation of a Fairbanks-Morse 9 cylinder, 38TD diesel rated at 2160 Bhp at 720 RPM. The diesel would generate 1530 kilowatts of electricity and provide 4.61×10^6 btu/hr of energy to the University heating plant. When in operation the system will meet the University's entire electrical demand. The system will be integrated with Massachusetts Electric Company. The utility has agreed to purchase electricity generated in excess of the University's demand and to sell electricity to the University when the generator is not in operation or otherwise unable to fulfill the University's demand. The thermal load of the University that exceeds the diesel's output will be provided by the present boiler system.

II. ACTIVITY DESCRIPTION

- A. Include an original 8½ x 11 section of a U.S.G.S. 7½ minute, 1:24,000 scale map with the activity or project area boundaries delineated. (Original U.S.G.S. sheet required for filing with Secretary only; copies may be supplied to others.) Include multiple maps if activity or project is larger than the area delineated on a U.S.G.S. 1:24,000 scale map. Include maps, diagrams or sketches at a larger scale if the features of the activity or project cannot be clearly shown at the 1:24,000 scale.**

- B. Give a brief description of the present use of the area or areas affected in 5.**

Indicate the number of acres affected that are:

1. Developed 0

3. Wetland ☐ ☐ ☐ ☐

- 2. Open Space** 0

4. Shoreline ☐ ☐ ☐

- 5. See Attached**

- C. Give a brief description of the proposed activity, including all phases and characteristics;**
In 2.

- 1. Fill in the following dimensions, if applicable:**

- a. Total Activity Area (Acres):

- d. Number of Stories:

	0
--	---

- b. Length in Miles:
		0

- e. Number of Parking Spaces:

- c. Number of Housing Units:

- f. Vehicular Traffic Generated Per Day:

--	--	--	--	--	--

- 2. See Attached**

- D. Describe how your agency is involved in the activity in 4.**

Specify:

- [illegible]

- 2. Pertinent Governing Statute(s) or Regulation(s):**

- 3. Other State Agencies Involved:**

- 4.

B. 5.

The present use of the area affected is (if OPTION 1) housing for the existing boiler system at the University. Location here will not alter the function of this area.

Outside (OPTION 2). Present use in this area adjacent to Jonas Clark can be described as a small open space plot. Location of the glass enclosed structure housing unit will, in the belief of this team, enhance the aesthetic value of this area.

C. 2.

The proposed action involves the installation and operation of one 1530 kw Fairbanks-Morse 9 cyl. 38TD diesel, 2160 Bhp at 720 RPM. The machine is expected to operate 7750 hrs/yr w/1100hrs of down-time /or maintenance

The rate of fuel consumption and exhaust specifications as supplied by the manufactures are as follows:

Fuel consumption: .36 lbs./BHP/HR.

Exhaust Specs.:	No _x	9.0 gr/BHP/HR
	CO	1.0 gr/BHP/HR
	HC+	0.4 gr/BHP/HR
	Particulate	.125 gr/BHP/HR
	SO ₂	1.66 gr/BHP/HR

It will continue to afford view of the Goddard Library as well as the Jonas Clark facade. As the structure itself will highlight the operation of the facility, an educational function -- for the University as well as the community -- will be served.

III. ASSESSMENT OF POTENTIAL ENVIRONMENTAL IMPACT

Answer the following questions by placing an "X" in the appropriate YES/NO space; consider activity, construction, operational, as well as indirect impacts.

Indicate under "Explanation" why significant impact is considered likely or unlikely to result.

A. OPEN SPACE AND RECREATION

1. Might the activity affect the condition, use or access to any open space and/or recreation area?

☒ NO ☐ YES

If YES, specify area(s) and acreage(s) affected:

- (1) _____
(2) _____
(3) _____
(4) _____
(5) _____

Acreage

Duration

Severity

Enter Code

2. Explanation:

No significant impact on use or access to any open space and/or recreational area is expected, as the location of the facility is not in or near any such area.

B. HISTORIC RESOURCES

1. Might any site or structure of historic significance be affected?

☒ NO ☐ YES

If YES, state level of historic significance:

--

Significance

--

Duration

--	--

Severity

2. Might any known archaeological site be affected by the activity?

☒ NO ☐ YES

If YES, specify duration and severity:

--

Duration

--	--

Severity

3. Might any known paleontologic site be affected by the activity?

☒ NO ☐ YES

If YES, specify duration and severity:

--

Duration

--	--

Severity

4. Explanation:

No significant impact is expected on any historical, archaeological or paleontological site as the location area has undergone previous excavation - piping, etc. - without damage to any of the above.

After checking with the necessary commissions it has been concluded that the project is not located in a sensitive area.

C. ECOLOGICAL EFFECTS

1. Might the activity affect any natural feature adjacent to or near the activity area?

If YES, specify natural features affected:

- (1) _____
 (2) _____
 (3) _____
 (4) _____
 (5) _____
 (6) _____

☒ NO ☐ YES

Duration	Severity	Enter Code	

2. Might the activity affect wildlife or fisheries?

If YES, specify wildlife or fisheries affected:

- (1) _____
 (2) _____
 (3) _____
 (4) _____

☒ NO ☐ YES

Duration	Severity	Enter Code	

If YES, specify whether any rare or endangered wildlife or fisheries species might be affected:

☒ NO ☐ YES

3. Might the activity affect natural vegetation?

If YES, specify vegetation and acreage(s) affected:

- (1) _____
 (2) _____
 (3) _____
 (4) _____
 (5) _____
 (6) _____

Acreage

Duration	Severity	Enter Code	

☒ NO ☐ YES

If YES, specify whether any rare or endangered plant species might be affected:

☒ NO ☐ YES

4. Explanation:

D. ENVIRONMENTAL HAZARDS

1. Might the activity involve the use, storage, release of, or disposal of potentially hazardous substances?

If YES, specify substance type and rate of usage:

- (1) _____
 (2) _____
 (3) _____

Usage Rate

☒ NO ☐ YES

Duration	Severity	Enter Code	

2. Might the activity involve alteration of riverine floodplains, inland wetlands, or coastal wetlands?

If YES, specify duration and severity of impact:

☒ NO ☐ YES

Duration	Severity

3. Might the activity involve construction or other action within geologically unstable areas?

 X NO YES

4. Explanation: Operation of this facility does not require the use, storage or release of potentially dangerous materials. In addition, its location is not near/on wetlands or a specifically unstable geological area. For these reasons, the facility is not regarded as posing a potential environmental threat.

E. RESOURCE CONSERVATION AND USE

1. Might the activity affect or eliminate land suitable for agricultural or timber production?

 X NO YES

If YES, specify present agricultural land use and respective acreage(s) affected:

- (1) _____
(2) _____
(3) _____

Acreage

Duration

Severity

Enter Code

2. Might the activity affect potential use or extraction of an indispensable or scarce mineral or energy resource?

 NO X YES

If YES, specify resource affected and approximate amount:

- (1) Oil _____
(2) _____
(3) _____

4	8	7

Tons

3

Duration

3	6

Severity

5	2	1

Enter Code

3. Explanation: As this facility is not located in an agricultural area, and any excavation would be to nominal depths (no more than 12') in a shale ledge, there are no expected impacts on any resources due to construction. However, operation of the ICES will result in a net savings of approximately 8,000 barrels of oil/yr. These savings are important in light of our national goal to decrease energy consumption.

F. WATER QUALITY AND QUANTITY

1. Might the activity affect the quantity of water resources, within, adjacent to, or near the activity area?

 X NO YES

If YES, specify water source affected and respective amount (gallons/day):

- (1) _____
(2) _____
(3) _____
(4) _____

Gallons/Day

Duration

Severity

Enter Code

2. Might the activity result in a deleterious effect on the quality of any water resource areas or watersheds?

 X NO YES

If YES, specify water resource that might be affected:

- (1) _____
(2) _____
(3) _____
(4) _____

Duration

Severity

Enter Code

If YES, specify possible substance causing effects:

- (1) _____
 (2) _____
 (3) _____
 (4) _____

Duration

Severity

Enter Code

3. Explanation:

G. AIR QUALITY

1. Might the activity affect the air quality in the project area, immediately adjacent areas, or the Air Quality Control Region?

If YES, specify possible substances affecting air quality:

- (1) Construction - Dust
 (2) Nitrogen Oxides (NO_x)
 (3) Particulate
 (4) Hydrocarbons (HC+)
 (5) Sulphur Dioxide (SO₂)
 (6) Carbon Monoxide (CO)

1
3
3
3
3
3

Duration

1	6
3	6
2	6
2	6
2	6
2	6

Severity

7	0	6
7	0	2
7	0	6
7	0	4
7	0	1
7	0	3

Enter Code

If YES, specify whether any key receptors may be in the affected area:

- (1) Educational Facility (Clark University)
 (2) _____
 (3) _____

3

Duration

2	6

Severity

7	2	3

Enter Code

2. Explanation:

See attached.

H. NOISE

1. Might the activity result in the generation of noise?

If YES, specify noise source:

- (1) Construction
 (2) Operation - i.e., cooling tower
 (3) _____

1
3

Duration

1	6
1	6

Severity

8	0	1
8	0	6

Enter Code

2. Explanation:

See Attached.

G. 2. Explanation:

The operation of the diesel will affect the air quality in the project area to a minor degree. Installation of a TEP will alter air pollution impacts, not only because the TEP based system will use less fuel, but more importantly because air pollution from internal combustion engines has a different character than that from furnaces. The greatest increase will be in amounts of NO_x emitted due to the high operation temperature of the equipment. The increase in emission is directly related to the increased capabilities of the new system and must be considered in light of possible reductions regionally owing to the overall expected decrease in oil consumption.

H. 2. Explanation:

The proposed project is expected to have an imperceptible noise impact on the environment. Noise levels inside the building will meet the OSHA standard of 85 DB. All measures will be utilized to insure against any disruption of the present environment, in and around, Clark University. Construction noise will be kept to a minimum through the use of heavily muffled equipment. No negative noise impact is expected during the operation phase owing to use of noise abatement materials in construction of, and around, the equipment housing.

I. AESTHETICS

1. Might the activity cause a change in the visual character in or near the activity area?

____ NO ☒ YES

If YES, specify natural and cultural features that may be changed:

- (1) Old man-made structure (if TEP is placed
 (2) outside)
 (3) _____
 (4) _____
 (5) _____
 (6) _____

4

Duration

2	6

Severity

9	0	1

Enter Code

2. Explanation:

See Attached.

J. PLANNING

1. Will the activity require a variance from or result in a potential violation of any statute ordinance, by law, regulation, or standard, the major purpose of which is to prevent or minimize damage to the environment?

☒ NO _____ YES

If YES, specify variances and/or statutes:

2. Will the activity require certification, authorization, review of plans, or issuance of a permit by any local, state or federal agency?

____ NO ☒ YES

If YES, specify agency and action required:

3. Will the activity comply with all federal, state and local land use, transportation, open space, recreation and conservation plans?

____ NO ☒ YES

If NO, state plan type and specific agency concerned:

- (1) _____
 (2) _____
 (3) _____
 (4) _____

Enter Code

4. Explanation:

I. 2. Explanation:

With the construction of a new building designed to house Clark's Total Energy plant, a part of the Jonas Clark structure, approximately 8 feet high and 40 feet long will be obstructed. It is the belief of the Environmental Group that aesthetic values added outweigh the loss arising from obstruction of the Jonas Clark side facade. This belief lies in our conviction that an attractive structure, as the one planned, allowing view of Plant operations, has greater aesthetic value than the small part of the facade that will be obstructed. In addition, this feature will enhance relations with the community surrounding Clark as the plant will provide an additional site of interest on the campus.

IV. FINDINGS AND CERTIFICATION

A. It has been determined that this project is not one which may cause significant damage to the environment (Negative Assessment).

☒

B. It has been determined that this project may cause significant damage to the environment (Positive Assessment).

☐

1. The draft impact report will be submitted on or about: _____

2. The draft impact report will be:

Standard

☐

Extensive

☐

3. The draft impact report will be combined:

☐

4. The draft impact report will be joint in conjunction with:

☐

C. I hereby certify that this assessment has been or will be, if applicable regulations provide for subsequent circulation, duly circulated to the Attorney General, the appropriate Regional Planning Agency, and other review agencies as required by Appendix B.

DATE

Signature of Responsible Officer

(print or type) Name of Responsible Officer

Address

Signature of Preparing Officer (If different from Responsible Officer)

Telephone Number

4. Individuals and Offices Consulted

Edmond G. Benoit
Chief, Air Quality Control Section
Central Mass Air Quality District

Tom Cusson
Central Mass Air Quality District

Al Nicks
Noise Pollution
EPA, Boston

John Lynch
E.I.S. Office
EPA, Boston

Linda Murphy
Air Quality: New Sources
EPA, Boston

Charles O'Connor
Office of Planning and Community Development
Worcester, Mass.

Norton S. Remmer, P.E.
Commissioner: Department of Code Inspection
City of Worcester, Massachusetts
419 Belmont St. 01604

APPENDIX 2B

Relevant Codes and Regulations

Separate Volume

APPENDIX 2C

Letters about Code Compliance

NORTON S. REMMER, P.E.
COMMISSIONER

City of Worcester, Massachusetts

DEPARTMENT OF CODE INSPECTION

419 BELMONT STREET 01604

TELEPHONE (617) 798-8111

Mr. Lawrence Landry
Vice President of Finance
Clark University
950 Main Street
Worcester, Mass. 01610

Dear Mr. Landry,

This letter will serve to confirm the conclusions reached at a meeting on Monday, April 11, 1977 relative to regulations controlling the proposed installation of mechanical facilities at Clark University in conjunction with an ERDA demonstration project.

1. Zoning. In accordance with the Zoning Ordinance of Worcester and the Official Map the proposed use would not be in violation of zoning and could proceed routinely for approval.
2. Building Code. There are no requirements of the Building Code relative to the proposed locations which were reviewed for which compliance could not be achieved by standard design and construction techniques.
3. All other requirements of the City relative to construction based upon the proposed preliminary concepts, would be subject to routine procedures.
4. This office cannot take responsibility for State mandated and administered requirements relative to environmental impact, and pollution controls. These items would have to be reviewed by the appropriate authorities.
5. Certain Boilers and Unifired Pressure Vessels require approval by the Board of Boiler Rules of the State Department of Public Safety as indicated in Sections 1100.11 and 1103.1 of the State Building Code, and this office would have no jurisdiction over those approvals.

Norton S. Remmer, P.E.
Commissioner

NSR/pf

TEL. (617) 791-3672

-219-

The Commonwealth of Massachusetts

Department of Environmental Quality Engineering

Central Massachusetts Air Pollution Control District

75 Grove Street

Worcester, Massachusetts 01605

May 11, 1977

Mr. Lawrence Landry
Vice President of Finance
Clark University
950 Main Street
Worcester, Massachusetts 01610

Gentlemen:

The Central Massachusetts Air Pollution Control District has reviewed preliminary data for the Phase I submittal to ERDA on the proposed Inter Connected Energy System (ICES) for Clark University, 950 Main Street, Worcester, Mass.

After a review of the available data and a conference with Mr. Harry Schwartz and Mr. Steve Sawyer of Clark University, it is the opinion of this office that the project as presently proposed, would not cause violation of existing air pollution regulations or standards. Should Clark University be a recipient of a grant for this project approval of final plans and specifications for both air quality considerations and noise would be required, but no problem is anticipated in either area.

Furthermore, this office considers such projects important to the community and New England as a whole and you can be assured of our cooperation in any areas where we may be of assistance.

Yours truly,

A handwritten signature in cursive script, appearing to read "Edmond G. Benoit".

Edmond G. Benoit
Chief, Air Quality Control Section

EGB:mlk

cc: Harry Schwartz

WORCESTER REDEVELOPMENT AUTHORITY

MEMBERS

EDWARD C. MAHER CHAIRMAN
RICHARD J. RUTHERFORD
VICE-CHAIRMAN
MILTON P. HIGGINS
TREASURER
WILLIAM F. SULLIVAN
ASST. TREASURER
JAMES B. LAVIN
ASST. SECRETARY

41 ELM STREET
WORCESTER, MASSACHUSETTS 01609

TELEPHONE
701-9231

May 13, 1977

Mr. Larry Landry, Vice President
Clark University
950 Main Street
Worcester, Massachusetts 01610

Dear Mr. Landry:

The Worcester Redevelopment Authority, as owner of properties in proximity to Clark University, has no objection to the installation of a central community energy system on the Clark University grounds.

Sincerely yours,

John J. Coughlin
Executive Director

JJC:d

MIRICK, O'CONNELL, DEMALLIE & LOUGEE
COUNSELORS AT LAW
1700 MECHANICS NATIONAL TOWER
WORCESTER CENTER
WORCESTER, MASS. 01608
617 799-0541

May 25, 1977

Lawrence L. Landry, Vice President for
Business and Finance
Clark University
950 Main Street
Worcester, Massachusetts 01610

Dear Mr. Landry:

You have inquired about the legal implications involved if the University proceeds with plans to construct, equip and operate an electric power generating facility designed to furnish the electricity ordinarily needed by the University, with provision by connection to the New England Electric System for sale to the System of any excess electricity generated by the University, and for purchase from the System of any electricity the University might need in addition to that generated at its facility.

Although the University has no express power to engage in the generation of electric power, I am satisfied that it has the implied power to do so for its own internal use. However, an arrangement involving the manufacture of electricity for sale requires consideration of several other issues. Those that occur to me are as follows:

First, even though the University may properly manufacture electricity sufficient to meet its own needs, it is possible to argue that the institution as an eleemosynary entity does not have the power to manufacture electricity for sale to others. In view of the facts that the principal purpose of the proposed facility is to provide the University with its own energy needs, that any sales of excess energy would be incidental and in lieu of wasting such excess, and that the public has a direct interest in conserving energy, I conclude that this possibility is a theoretical rather than a practical cause for concern. If necessary, the University could seek a ruling from the Attorney General, or legislative approval, or separately incorporate a subsidiary to operate the facility.

Second, by definition, engaging in the manufacture and sale of electric current would bring the activity within the jurisdiction of the State Department of Public Utilities, (Massachusetts General Laws chapter 164), and require conformance with the applicable statutes and the rules and regulations of that Department. Discussion with appropriate officials of the

May 25, 1977

Department will be necessary to determine the ramifications. I understand that the New England Electric System will support the University's venture and our contact there indicates that the Department will help rather than hinder the project.

Third, the conduct of the facility by the University may be construed as engaging in an unrelated business activity by the Internal Revenue Service. In view of the limited and incidental nature of the business activity, I do not think there will be any questions about the continued exempt status of the University as a qualified public charity. In the absence of Federal legislation exempting the type of proposed activity, I would urge filing a request for a ruling from the Service on the point.

Fourth, on the local level, I understand that the zoning officials do not foresee any zoning problem. However, the activity may subject the real estate and equipment used for the purpose to local real estate and personal property tax. Possibly the activity would necessitate obtaining one or more licenses or permits not now required. I understand that in preliminary discussions, local officials have indicated their willingness to cooperate in making the facility possible.

In any case, it seems likely that it may take several months to resolve the issues.

I trust the foregoing will be of assistance.

Very truly yours,

Richard W. Mirick

RWM/pjb

APPENDIX 2D

Information Dissemination: Abstracts of Papers to Date

Presented at the National Conference on Technology for Energy
Conversion, Washington, D.C., June 8-10, 1977

Energy Profiles at Clark University: Implications for Cogeneration *

R. Collins, R.L. Goble, and A.M. Gottlieb

Department of Physics and Program on Science, Technology, and Society
Clark University, Worcester, Massachusetts, 01610

Abstract

Cogeneration, electricity generation with heat recovery, shows great promise for conservation. Because a variety of cogeneration technologies are available today and can be retrofitted to a large number of existing industrial and residential sites, this promise could be realized soon.

Best use of the potential for cogeneration requires that sites consuming large amounts of low temperature heat be able to export electricity. Industries using process steam extensively will produce electricity at a fairly constant rate, thus making a well defined contribution to utility capacity. For this reason studies of cogeneration have concentrated on industrial facilities. Still it would be wrong to neglect residential communities. Large amounts of heat are used for space conditioning and hot water, so there is a substantial potential for energy conservation through cogeneration. There will, however, be a significant variation of electrical capacity with season and time of day.

In this paper we report energy use profiles for a test community, Clark University, and show the variation in electric output of sample cogeneration systems with time and weather. Clark is a small university serving 2,500 people during the day and 1,200 at night. It is typical of many northeastern residential communities in size, population, and energy use. We find, as expected, that electricity output will depend importantly on weather and occupancy patterns. However, Clark's peaks in output match quite well the daily and seasonal peaks in demand on the local electric utility. As Clark is similar in occupancy and heat load to many residential communities, we expect that cogenerated electricity from such communities could quite usefully be incorporated in utility capacity development.

*Research supported in part by ERDA contract # EC77-C-02-4211

Abstract of Paper to be Presented at the International Conference on
Energy Use Management, Tucson, Arizona: October 24 through 28, 1977

Grid-Connected Cogeneration at Clark University:
The Effect of Terms of Utility Interconnection*

Robert L. Goble

Dept. of Physics and Program in Science, Technology, and Society
Clark University
Worcester, MA 01610

Sander E. Nydick

Energy Systems Division
Thermo Electron Corporation
Waltham, MA 02154

Cogeneration offers great promise both as a way of saving energy and as a relatively economical source of new electrical generating capacity. Its promise can be fully realized, however, only if cogeneration facilities easily interchange electricity with the utility grid. In this paper we compare cogeneration alternatives for a test community, Clark University, and show that the choice of type and size of system is very sensitive to the terms of interchange.

The Clark campus, a small urban campus with around 2500 daytime users and 1200 residents, is typical in size and energy use of a large number of New England residential and commercial facilities, including, of course, many colleges and universities. The cogeneration systems we compared are all commercially available. We looked at a wide range of heat and electricity outputs and considered systems both dependent on and independent of electric utility interconnection. We find that differences in the price schedule for exported electricity can have a large effect on the amount of electricity a community like Clark would be willing to generate. There are several possible strategies: (1) the community can continue to be a normal utility customer; (2) it can make some, most, or all of its electricity; (3) it can make most or all of its electricity and export some electricity, choosing its electric

capacity, however, only to meet its own electric needs; or (4) it can make most or all of its own electricity and have sufficient excess electric capacity to make substantial exports. There could be a ratio of 8 or more between the outputs under (4) and (2). Hence policies or regulations affecting interchange will have a big impact both on the future amount of energy saved through cogeneration and on the availability of this source of generating capacity.

We present a progress report on Clark's negotiations with the New England Electric System. Then we look in detail at the strategies Clark might pursue, their financial impact on Clark, and the amounts of energy involved for a range of conceivable prices and terms.

* Research supported in part by ERDA contract #EC77-C-02-4211

APPENDIX 3A

Protective Circuits Required in the Grid Connection

NEW ENGLAND POWER SERVICE COMPANY

20 Turnpike Road, Westborough, Massachusetts 01581

June 30, 1977

Dr. Robert L. Goble
Physics Department
Clark University
Worcester, MA. 01610

Subject: ERDA - Clark Grid Connected ICES Feasibility Study

Dear Bob:

The following comments are provided to present the minimum protection system required by Massachusetts Electric Company (Masselec) for the interconnection between Masselec and Clark University (Clark) pertaining to proposed installation and parallel operation of a 1500 KW diesel generator by Clark. Also included are comments relative to the metering arrangement needed for the interchange of power between Masselec and Clark.

1. Masselec's present policy is to make no changes at our substations when customers operate generators in parallel with us, except to remove any instantaneous reclosing devices. We will retain slow speed reclosing and make no check as to whether the feeder is alive or dead. We expect the customer to trip for faults and not keep the line energized. The customer (Clark) will do all synchronizing of the generator. Furthermore, Masselec will do all the work required in the substations, at the customer's expense.
2. Generation by Clark on cable 20 is a problem because of the existing pilot wire protection. In 1968 when the connection (as an emergency source) was established, Masselec accepted the risk of tripping the Webster Street and Faraday Street terminals for a Clark University fault. However, when generating on cable 20, the circuit may be tripped for all faults in the Worcester area on the 13.8 kV system. There are two alternatives to overcome this problem:

- a. Clark to install a pilot wire terminal at the University with the connecting control cable, making a three terminal line. This is the recommended procedure.
 - b. Masselec to prohibit the parallel operation of the generator when Clark is connected to cable 20.
3. Masselec recommends that Clark operate the generator ungrounded since we only have a single ground source at Webster Street, with reactors in the neutral. Clark may install a neutral resistor or reactor as long as you are aware of the fact that you will share the neutral current flowing with Webster Street. Masselec would like to retain the existing non-directional ground relays with a pickup of 240 amps at Webster Street and 120 amps at Clark University on cable 41.
4. The existing non-directional overcurrent relays will continue to protect for Clark's phase faults. The pickup is 240 amps, which limits the load to about 5700 kVA in either direction on either 41 or 20.
5. A set of directional overcurrent relays should be installed to trip the 41 circuit breaker or the 20 circuit breaker for phase faults on these circuits. These should be set on 96 amps maximum in order to be sure the generator is capable of tripping the breaker. This limits the generation output to Masselec at 2300 kVa, which is above its rating. The 0.8 tap with 120 CT ratio will carry over 3 amps secondary or 360 amps primary in the non-trip direction. The directional overcurrent relays require 120 volts phase to phase.
6. For ground faults with an ungrounded source, Masselec prefers the installation of an overvoltage relay supplied from a set of auxiliary potential transformers with a broken corner delta connection which produces triple zero sequence voltage during a ground fault. The sides of the delta can be either 69 volts (producing 270V maximum) or 120 volts (producing 360V maximum).

7. Masselec requires customers with generation larger than their minimum load to have under and overvoltage relays plus under and overfrequency relays. The voltage relays only need to be single phase, although it is a little safer to have two or more undervoltage relays in case of a fuse blowing or single potential transformer failure. Relative to Clark, these relays would protect other customers on cable 41 or 20 from having the wrong voltage or frequency when isolated from Webster Street or Faraday Street.
8. Since the bus potential transformers must be connected wye grounded-wye for the ground detection overvoltage relay, there is a possibility of ferroresonance if the bus is operated or becomes ungrounded. The probability of this becomes remote if the potential transformers are loaded with at least 100 watts per phase. This is indicated on the attached sketch as a resistor marked R.
9. The above relay settings would be supplied by Masselec. Masselec must either set and test the relays or witness the setting and testing, both at your expense. You would be required to furnish us the drawings and data necessary to check the protection and calculate the settings. There must be a battery available for tripping the circuit breakers. The generator should be equipped with an automatic voltage regulator.
10. The following relay list supplements the information presented above, as well as the attached sketch. The relays are Westinghouse Electric Corporation, but equivalent types may be used, except for the pilot wire relay which must match that which is used by Masselec. Also, the directional overcurrent relay must have an 0.8 amp tap or lower.

<u>QTY.</u>	<u>Device</u>	<u>Function</u>	<u>Type</u>	<u>Range</u>	<u>Style #</u>
1	87PW	Pilot wire	HCB	4-15	292B930A10
1			Transformer	4/1	1575394
1			W2 Switch		508A468G01
1			RC Milliammeter		291B318A09
6	67-51	Dir. Overcurrent	CR-7	0.5-2.5	288B571A12
1	27		CB-2	55-140	1875508
1	59		CV-5	55-140	1875512
1	81-U		KF	55-59.5	671B287A15
1	81-O		CF-1	55-65	291B995A12
1	59N		CV-5	55-140	1875512
6	Auxiliary transformers 120/69 volts at least 50VA.				
3	Loading resistors, adjustable, set approximately 150 ohms, rated 200W, if generator is not grounded.				

11. The metering requirements are presented in the attached sketch. This metering equipment will be supplied and installed by Masselec at Clark's expense.
12. Finally, the information presented above is subject to change, depending on any additional material provided by you.

If you have any questions, please contact this correspondent; or, in his absence, Mr. John T. Casey.

Very truly yours,

Ronald W. Plutnicki, P.E.
Consumer Services Consultant

RWP:CL
Enclosures

Note 1. This shows the existing 3-wire, 13.8 kV metering arrangement. A third meter would be required for conventional IN-OUT metering of kWh. Two more meters would be required for IN-OUT metering of KVARH.

Two (2) DPR's (Digital pulse recorders) will be required. This metering arrangement assumes that there will be no grounded loads. If there are grounded loads, meters and instrument transformers will have to be changed accordingly.

APPENDIX 4A

Letters Confirming Agreements and Terms to Date

Energy Systems

101 First Avenue
Waltham, Massachusetts 02154
(617) 890-8700

Telex: 92-3323
Cable: TEECORP

November 12, 1976

Mr. Lawrence Landry
Vice President
Clark University
Worcester, Massachusetts 01601

Dear Mr. Landry:

Thermo Electron Corporation is pleased to join with Clark University as a subcontractor in submitting a proposal in response to the Energy Research and Development Administration's Proposal No. E(11-1)P-76-0016, "Demonstration of a Grid-Connected Integrated Community Energy System".

Thermo Electron's contributions to Phase I of the proposed program are in the following tasks:

- Task 1 - Preliminary Energy Analysis
- Task 3 - Conceptual Design
- Task 5 - Detailed Work Management Plan

Work statements for these tasks and Thermo Electron's contributions are described in detail in Section 6.0 of the proposal (Phase I PERT Chart and Manpower Schedule).

It is understood that the type of contract between Thermo Electron and Clark University in this work will be a cost reimbursement level of effort contract encompassing 8 man months of effort at a cost of \$52,998 as specified in the attached Contract Pricing Proposal.

In the event that ERDA contracts with Clark University for Phases II-VI after the successful completion of Phase I, Thermo Electron would be pleased to provide support in the areas of power plant and component design, procurement specifications, construction and installation planning management, system start-up, and performance test analysis. Our responsibilities in these areas would be as suggested in Section 6.0 of the Proposal (Phase II-IV PERT Chart).

Mr. Lawrence Landry

Page 2

November 12, 1976

We are looking forward to collaborating with you on this program and believe that our experience in power plant systems and fuel conservation will insure that the power system installed under this demonstration program will be economical, reliable, and fuel conserving providing Clark University with its utility requirements as well as serving as a national demonstration show piece of a community grid-connected energy system.

Sincerely,

Jerry P. Davis
Manager
Energy Systems

JPD:j11

MASSACHUSETTS ELECTRIC COMPANY 20 Turnpike Road, Westborough, Massachusetts 01581

May 11, 1977

Mr. Mortimer H. Appley, President
Clark University
Worcester, Massachusetts 01610

Subject: "Clark-ERDA, Demonstration of a Grid-Connected
Integrated Community Energy System"

Dear Mr. Appley:

I have been advised of the time schedule for Clark's final Phase I report to ERDA. To assist your Task Group in preparing the final draft, the following is a summary of Massachusetts Electric's position regarding this project:

A. Proposed pricing arrangement for purchase of Clark's excess electricity by Massachusetts Electric Company (Masselec). (Masselec is an operating company of New England Electric System (NEES) and its power is supplied by New England Power Company, another NEES subsidiary)

1. Masselec is willing to enter into contractual agreement with Clark to purchase the excess electricity from the co-generation plant for the life of this project. The pricing for the purchases would be at a rate approximating the cost of fuel saved by backing down New England Power Company generation supply. The payment will be defined by Masselec on a monthly basis, as follows:

(Weekdays, 7:00 a.m. to 11:00 p.m.) \$/kwh = A x 1.30

(Weekdays, 11:00 p.m. to 7:00 a.m.) \$/kwh = A x 1.06

(Weekends and Holidays, 24 hours) \$/kwh = A x 1.06

A = average New England Power Company (NEP) Fuel Costs for the current operating month.

For the purpose of this study, A is projected to be approximately \$.017 (17 Mills) per kwh for 1977; and for the period 1981 to 1982 to be in the range of \$.020 (20 Mills) to \$.025 (25 Mills) per kwh.

1.30 & 1.06 = multipliers used to convert average fuel costs to incremental fuel costs. These multipliers are subject to modifications to reflect changes in the relationship between average fuel cost and incremental fuel cost.

2. Masselec is not in the position to make commitments for new capacity at this time because our future growth rate is uncertain. Also, we have commitments which appear adequate to meet our capacity needs into at least the early 1980's.
3. The effect of a Clark ICES installation might impact upon other Masselec operating costs; but, the incremental effect of a single installation would be very small and very difficult to estimate.

B. Proposed pricing arrangement for the purchase of electricity by Clark from Masselec.

Preliminary investigations show that there may be times when Clark would be purchasing electricity from Masselec. In previous correspondence, your Task Director was advised that service from Masselec would be in accordance with existing Auxiliary Service Provisions. These provisions call for a minimum monthly charge, which can be used up with the purchase of electric energy.

Our current thinking is toward the use of a facilities charge, which would be in addition to the cost of energy. It is our feeling that the pricing for auxiliary service may not adequately compensate our companies for the capacity that must be counted on for standby purposes. Following this thinking, pricing for the purchases made by the co-generator must be reviewed in greater detail.

C. Proposed Grid Interconnection Scheme.

As you are aware, the new electrical connection between Clark and Masselec, which would allow for an interchange of power, would be at Clark's expense. Our engineers are now reviewing this situation, based on information recently furnished by your Task Director. We will have available a preliminary scheme and estimate of costs for the Task Group's meeting with ERDA officials on May 26.

Mr. Mortimer H. Appley
May 11, 1977
Page Three

-239-

D. NEES Philosophy on Co-Generation.

We are in the process of developing a company policy for the co-generation customer. As our ideas begin to jell and a firm attitude takes hold, we shall notify your Task Director.

I trust this letter will provide the necessary input for your Task Group's final report.

Sincerely,

A handwritten signature in dark ink, appearing to read 'J.R.S.', with a long horizontal flourish extending to the right.

John R. Stevens
Vice President

JRS:CL

cc: Dr. Frank W. Puffer, Program Administrator
Dr. Robert L. Goble, Task Director

APPENDIX 4B

Present Auxiliary Power Provisions

MASSACHUSETTS ELECTRIC
COMPANY

AUXILIARY SERVICE PROVISIONS

AVAILABILITY

Service is available under any applicable filed rate of this Company for Auxiliary Service, sometimes referred to as Standby or Breakdown Service, and more fully defined as service available at all times to a Customer having another source of power, electrical or mechanical, from which to supply his requirements of light, heat or power, or a portion thereof. Where such other source is used only in case of failure of the Company's service, the Company's service shall not be considered as Auxiliary Service.

RATE

The charge for electricity shall be computed under the Rate applied with this Provision, but not less than \$1.75 per month per KVA of contractual transformer capacity.

TERM OF AGREEMENT

The agreement for service under this rate will continue for an initial term of one year if electricity can be supplied to a Customer without an uneconomic expenditure by the Company. The agreement may be terminated at any time on or after the expiration date of the initial term by twelve months' prior written notice; provided, however, the Customer by written notice to the Company may terminate Auxiliary Service at any time should the Customer permanently abandon the operation of his own source of power.

TERMS AND CONDITIONS

The Company's Terms and Conditions in effect from time to time, where not inconsistent with any specific provisions hereof, are a part of this rate.

Effective December 1, 1971.