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FEASIBILITY OF MEETING THE ENERGY NEEDS OF ARMY BASES WITH SELF-GENERATED FUELS DERIVED FROM SOLAR ENERGY PLANTATIONS

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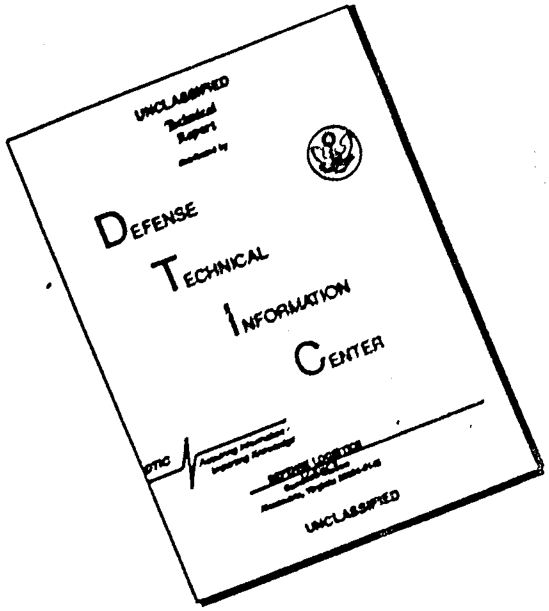

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This project thoroughly investigated the possibility of collecting and storing solar radiation in plants especially grown for their fuel value as a source of fuel on U. S. Army bases.

The study investigated the merit of producing this fuel at energy plantations at or near the bases. The fuel would be used for directly fired steam generators, hot water heaters, space heaters, and cooking. ~over

Block 20 continued.

The research examined the major characteristics of energy plantations; analyzed plant-matter production rates from deciduous plants; and examined fuel consumption in stationary facilities at major troop training centers. The possibilities and requirements of energy plantations at Fort Benning, Fort Leonard Wood, and at Army bases in general were detailed.

It was concluded that energy plantations could be feasible at approximately 15 large Army bases and that the cost of solid fuel produced from them would be approximately $1/1 million Btu; the cost of synthetic natural gas produced from plants was determined to be approximately $3.10 to $4.20/1000 standard cu ft.

Besides being a perpetually renewable fuel source, it was found that energy plantations could provide independence from other fuel sources, reduction in future environmental problems caused by present fuels, and will productively use land not now in active use.

FEASIBILITY OF MEETING THE ENERGY NEEDS OF ARMY BASES WITH SELF-GENERATED FUELS DERIVED FROM SOLAR ENERGY PLANTATIONS

A thorough investigation of the possibility of "home-grown" perpetually renewable fuel generated on U. S. Army bases from plant material, especially at Forts Benning and Leonard Wood, has been made.

The major conclusions from the study are:

1. Energy Plantations are feasible for meeting the fuel needs for fixed facilities in at least fifteen large Army bases in the eastern and central time zones;
2. the cost of solid fuel produced in Energy Plantations will be about one dollar per million Btu, and the cost of SNG will be between about $3.10 and $4.20 per thousand standard cubic feet, although there is some uncertainty associated with these cost figures, particularly the technology for producing SNG from plant material;
3. plant species which are most suitable for "Btu Bushes" at the Army bases have been identified;
4. immediate steps to study the remaining open questions and to commence Energy Plantation system design should be taken; and
5. by implementing the program, several significant benefits can accrue:
    a. natural-gas shortages and possible unavailability will not affect continued operations at the Army bases;
    b. U. S. Army technological leadership in adaptation to future energy-tight conditions will be clear; and
    c. essential military training and readiness will not be totally dependent on fossil-fuel supplies and in competition with civilian needs.

ACKNOWLEDGEMENTS

While the names of the principal investigator and program manager are shown on the cover page, the names of the others who contributed to the successful completion of this work are not. They deserve personal recognition too - so here they are:

Dr. Malcolm D. Fraser
Dr. Jean F. Henry
Dr. Santosh Kumar
Mr. Charles W. Vail
Miss Debra L. Shenk

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I. SUMMARY

An Energy Plantation is a means for producing fuels by collecting and storing solar radiation in plants grown purposely for their fuel value on a large scale. The harvest from the plantation might be used directly as a solid fuel, or it can be processed into some other fuel form. Apart from being an inexhaustible source of fuel replacing increasingly scarce and expensive fossil fuels used at Army bases, Energy Plantation systems have other attractive features. They provide independence from unreliable sources of fuel and reduction in future potentially very serious environmental problems. Energy Plantations will also create a valuable use in some instances for land which is not very actively used at present.

The study has investigated the merit of supplying the fuel consumed at Army bases in fixed installations by producing it in Energy Plantations at or near the bases. Fuels considered are those used in directly fired steam generators, hot-water heaters and space heaters and for cooking. Fuels used for generating electricity in fixed generating facilities at bases are therefore included. Fuels used in mobile and transportation equipment or fuels consumed for producing electricity purchased from sources outside Army bases are not considered.

After allowance is made for climate, topography and population density, it is concluded that Energy Plantations can reasonably be considered for major Army bases in unurbanized localities almost anywhere in the eastern and central time zones except for the Appalachian Mountain area and the densely populated corridor extending along the Atlantic seaboard from northern Virginia to New Hampshire. In the light of these conclusions, fifteen large Army installations shown in Table I are in localities technically suitable for consideration for Energy Plantations.

The feasibility of Energy Plantations at Army installations in unurbanized areas depends on being able to produce at least seven to ten dry tons of harvestable plant material per acre per year on land at or near the bases. About twenty identified species and varieties of fast-growing deciduous trees meet these yield requirements when they are grown in dense plantings (5,000 to 11,000 plants per acre), and the stands are harvested at two to three-year intervals five or more times from stump regrowth after the first harvest. Several warm-season grasses grown in Florida and near the Gulf coast also meet the yield requirement. At least one of these deciduous or grass species can generate plant matter at the required rate at every Army base suitable for Energy Plantations shown in Table I.

The plant material grown in Energy Plantations may be used as a solid fuel after it is partially dried, or alternatively, it may be converted into a gaseous or liquid fuel by pyrolytic or biological processes. It is concluded that using the product of Energy Plantations either directly as a solid fuel in a central heating system or converting it to synthetic natural gas are the only two final-fuel-form possibilities which merit further consideration.

Analysis of fuels consumption and direct-fired equipment at troop centers in the lower forty-eight states reveals that Fort Benning and Fort Leonard Wood are representative of Army bases in unurbanized areas, and conclusions drawn for them with respect to the feasibility of Energy Plantation systems are broadly applicable to the other major Army bases.

The estimated cost of solid fuel produced in plantations is about one dollar per million Btu (see bottom of Table II). This cost is substantially below the present costs of light and heavy fuel oils everywhere, and of coal in many localities. The estimated cost of SNG produced from plant

TABLE I

TECHNICAL SUITABILITY OF SELECTED LARGE ARMY INSTALLATIONS FOR ENERGY PLANTATIONS

Installation	Suitable	Probably Unsuitable and Reason Therefor
Fort Polk, La.	●	
Fort Hood, Texas	●	
Fort Stewart, Ga.	●	
FORT BENNING, GA.	●	
Fort Gordon, Ga.	●	
Fort Jackson, S.C.	●	
Fort Bliss, Texas		Low Precipitation
Fort McClellan, Ala.	●	
Fort Bragg, N.C.	●	
Fort Sill, Okla.	●	
Fort Huachuca, Ariz.		Low Precipitation
Fort Campbell, Ky.	●	
Fort Knox, Ky.	●	
FORT LEONARD WOOD, MO.	●	
Fort Dix, N.J.		Densely Populated Area
Fort Riley, Kans.	●	
Fort Lewis, Wash.	●	
Fort Carson, Colo.		Low Precipitation
Camp Drum, N.Y.	●	
Fort Greely, Alaska		Climate
Fort Richardson, Alaska		Climate
Fort Wainwright, Alaska		Climate

Source: Appendix B

TABLE II

SUMMARY COMPARISON OF TWO ENERGY PLANTATION SYSTEMS

(Costs are in December 1974 Dollars)

	AT FORT BENNING		AT FORT LEONARD WOOD	
	Central Heating System Solid-Fuel-Fired	SNG System	Central Heating System Solid-Fuel-Fired	SNG System
Area of base - acres	182,000	182,000	106,000	106,000
Plantation Area - acres	25,000	32,000	22,000	29,000
Plant Material - dry tons per year	220,000	280,000	180,000	240,000
Manpower requirements:				
Plantation - full-time	95	147	79	127
Plantation - 6 months per year	34	43	28	37
Central Heating or SNG System - full time	98	108	88	93
Manpower totals:				
full-time	193	255	167	220
6 months per year	34	43	28	37
Capital Costs (see footnote 1):				
Establishing and equipping plantation - $	6×10^6	8×10^6	5×10^6	8×10^6
Central heating facility - $	43×10^6		35×10^6	
SNG production plant - $		31×10^6		25×10^6
Total System Capital Cost - $	49×10^6	39×10^6	40×10^6	33×10^6
Annual Costs (see footnote 1):				
Central heating system - $	7.4×10^6		6.3×10^6	
SNG production system - $		10.6×10^6		8.0×10^6
Capital Costs (see footnote 2):				
Establishing and equipping plantation - $	6×10^6	7×10^6	5×10^6	6×10^6
Central heating facility - $	43×10^6		35×10^6	
SNG production plant - $		22×10^6		17×10^6
Total System Capital Cost - $	49×10^6	29×10^6	40×10^6	23×10^6

TABLE II (continued)

SUMMARY COMPARISON OF TWO ENERGY PLANTATION SYSTEMS

(Costs are in December 1974 Dollars)

	AT FORT BENNING		AT FORT LEONARD WOOD	
	Central Heating System Solid-Fuel-Fired	SNG System	Central Heating System Solid-Fuel-Fired	SNG System
Annual costs (see footnote 2):				
Central heating system - $	7.4×10^6		6.3×10^6	
SNG production system - $		8.8×10^6		6.5×10^6
Unit costs of fuel value:				
Plant material as solid fuel - $\$/10^6$ Btu	1.08	0.97	1.09	1.01
SNG production system (footnote 1) - $\$/10^6$ Btu		4.20		3.70
SNG production system (footnote 2) - $\$/10^6$ Btu		3.50		3.10

Footnote 1: Capital and annual costs for SNG production plants based on state-of-the-art from the literature. Annual costs include the cost of replacing worn-out equipment.

Footnote 2: Capital and annual costs for SNG production plants based on anticipated improvements in performance. Under these circumstances, the plantation areas required will be reduced to about 27,000 and 24,000 acres for Forts Benning and Leonard Wood, respectively.

material is equal to or less than the estimated costs being announced these days for producing it from coal. It is probable that the costs of conventional fuels will rise more rapidly in the years to come than will the costs of fuels based on plant material grown in Energy Plantations. Therefore, the cost of the latter will almost certainly continue to become relatively even more attractive than those of the former in the next few years. These findings are the basis of the recommendation that development of Energy Plantations for Army bases be pursued promptly and seriously.

The estimated capital cost of central heating systems using solid fuel from Energy Plantations is moderately higher than the corresponding cost based on the state-of-the-art for producing SNG from plant material. The estimated annual costs, including provision for the cost of replacing worn-out equipment, for central heating systems using solid fuel from Energy Plantations are significantly lower than those for SNG systems based on the state-of-the-art (see Table II).

It is believed, however, that the state-of-the-art in the literature may substantially understate the probable performance of SNG systems. When allowance is made for this possibility (see Table II again), the estimated capital cost of SNG facilities is only about two-thirds of the corresponding cost for central heating systems, and the annual costs for the two systems become far more comparable. This finding leads to the recommendation that the production of SNG from plant material of the types proposed for growth in Energy Plantations be investigated on the laboratory scale.

II. CONCLUSIONS

A. Energy Plantations are a feasible means for meeting the fuels requirement for fixed facilities in at least fifteen large Army bases in the eastern and central time zones and for sheltering their operation from the growing effect of scarcity and cost of fossil fuels. Development of Energy Plantations for this purpose must therefore be pursued.

B. Two Energy Plantation systems merit consideration--using plant material grown under plantation conditions as a solid fuel in central heating systems, and converting the plant material to synthetic natural gas in facilities on Army bases.

C. The estimated cost, as a solid fuel, of plant material grown in plantations is about one dollar per million Btu, and is therefore very much cheaper than the present costs of light and heavy fuel oils everywhere, and of coals in many localities. If the plantation is operated for the Army by a contractor, this cost may be 30 to 50 percent higher.

D. The estimated cost of SNG produced from plant material harvested from plantations is between three and four dollars per million Btu, and is hence about equal to the costs being announced these days for the cost of SNG from coal. There is a great deal of uncertainty associated with these cost estimates, however, due to the uncertainty in the technology of producing SNG from plant material.

E. The estimated capital cost of the central heating and steam-distribution systems necessary at Army bases, if plant material is used as a solid fuel, is over thirty percent higher than the corresponding costs for facilities designed using state-of-the-art information for producing SNG from plant material. The annual costs of the central heating systems, however, are about twenty-five percent less than the corresponding costs for state-of-the-art SNG systems.

F. There is good reason to believe that the state-of-the-art understates the probable performance of SNG facilities. When allowance is made for this possibility, the capital cost of SNG facilities may be as low as a little more than half of the corresponding cost for central heating systems, and the annual costs of the two systems become far more nearly comparable.

G. Until production of SNG from the harvest of Energy Plantations is studied at least briefly in the laboratory, it will not be possible to decide whether Energy Plantation systems which produce SNG or which consume plant material as a solid fuel in central heating plants will be better for Army bases.

H. Certain deciduous woody species grown at high planting density and repeatedly harvested from stump regrowth, and warm-season grasses are the preferred species for cultivation in Energy Plantations.

I. Energy Plantations can be established on land which may not be very actively used at troop training centers (near the perimeter, for instance).

J. Significant environmental advantages with respect to sulfur oxide emissions and atmospheric thermal balance appear achievable.

K. U. S. Army leadership toward attainment of desirable national goals is a direct by-product of the reduction to practice of the Energy Plantation concept at Army bases.

III. RECOMMENDATIONS

A. Energy Plantation systems appear to have the potential to be a more reliable and less costly way in the future for meeting the fuels requirement in stationary facilities at many large Army bases in unurbanized locations than continued reliance on fossil fuels. However, further study of Energy Plantation systems for Army bases must be pursued, and further effort along the lines of recommendations B and C is needed before a definitive statement can be made.

B. The goal of the next phase in the development work should be collection of process data for:

1. deciding whether SNG Energy Plantation systems or central heating systems fired with plant material used as a solid fuel are the more appropriate for Army bases, and
2. designing a demonstration-scale Energy Plantation system of the type determined to be preferred as a result of the preceding point.

C. Work in two directions should be started promptly in support of recommendation B:

1. with respect to SNG Energy Plantation system, a program in the laboratory to develop process design data with special emphasis being given to:

   a. the methane yield per pound of plant material digested, and
   b. the relationships between the energy used for grinding plant material prior to its anaerobic digestion and

the fraction of the plant material rendered soluble in water, the rate of biological digestion of the ground plant material, and the pumpability of slurries in water of the ground plant material.

2. with respect to the growth rate of deciduous plant material under Energy Plantation conditions:
   a. a program in the field at a site similar to one at which a demonstration-scale Energy Plantation facility might be built to confirm plant-material growth-rate predictions and to generate locally adapted plant reproduction stock,
   b. a program in cooperation with those who are already growing species, under plantation conditions, of potential interest for Energy Plantations to assure that yield and plant-survival data are collected and made available for use in recommendation B,
   c. a program extending the search for plant species specially suited for Energy Plantation culture in the vicinity of Army bases in the eastern and central time zones; and
   d. a program to broaden the scope of the model for predicting the growth rate of deciduous species under plantation conditions to better allow for local climate and other major factors which influence the rate of plant-material growth.

IV. INTRODUCTION

IV.A. Background. Substantial amounts of fuel oil and natural gas are used for heat in stationary facilities at troop training centers and other large installations operated by the Army in the United States. There is sufficient land on or near many of the installations to accommodate Energy Plantations capable of supplying the entire fuels requirement for fixed facilities at these installations. It is in the national interest, in view of the dwindling reserves of oil and natural gas in this country, to find out whether Energy Plantations systems, in fact, are a feasible means for supplying the fuels used in fixed facilities at a significant number of these sites.

Energy Plantations are worthy of consideration for this purpose. They create an inexhaustible source of fuel by collecting and storing solar radiation in plant material grown explicitly for its fuel value. By choosing the appropriate plant species, planting density and harvest schedule for each plantation, the cost of the plant material produced can be minimized while attaining a high plant-material production rate, and therefore, coincidentally, a high fuel-value accumulation rate. Moreover, the harvest from the plantation can be used directly as a solid fuel, or be converted into another fuel form before being used.

The energy collected by plants from the sun is available for use even when the sun is not shining, because, in addition to absorbing solar energy, growing plants store it also in the plant material they have produced. Among land-based systems for collecting solar energy, only hydropower shares this naturally endowed ability to store solar radiation more or less indefinitely for subsequent use at our will.

IV.B. Objectives. The objective of the work is to assess the feasibility of using fuels produced from plant material grown in Energy Plantations in place of the fuels currently burned in directly fired stationary equipment at large Army bases in unurbanized localities. It is contemplated that the Energy Plantations would be located either on the bases or in the immediate vicinities of the bases. The work is to be:

- explicit enough to make detailed feasibility analyses of Energy Plantation systems for two broadly typical, large, dissimilar Army bases in unurbanized localities--Forts Benning and Leonard Wood have been chosen for this purpose; and
- broad enough to permit conclusions to be drawn about the general feasibility of Energy Plantation systems for large Army bases in unurbanized localities in the United States.

The conventional fuels which would be replaced by fuel from Energy Plantations are used these days at Army bases for directly fired steam generators, water and space heaters, and for cooking. Any fuels used for generating electricity in stationary facilities on the bases are included among those which would be replaced by fuels produced from Energy Plantations. Fuels used in mobile and transportation equipment are not included among the fuels which might be replaced, nor are the fuels used for generating electricity purchased by the base from the outside.

IV.C. Approach

IV.C.1. General Considerations. Since it was obvious before the work started that the plantations would necessarily require relatively extensive tracts of land, consideration has been limited to large training centers in unurbanized localities. The word "large" as used as a modifier for "training centers" means that the land area within the perimeter of the center is at least fifty square miles (32,000 acres), and the annual fuel consumption in stationary facilities is at least 200 billion Btu (the equivalent of 200 million standard cubic feet of natural gas or about 33,000 barrels of fuel oil per annum).

IV.C.2. Analysis of Fuel Requirements for Fixed Installations at Major Troop Training Centers

IV.C.2.a. Fuel Requirements. Because any Energy Plantation systems proposed must meet the end-use requirements served by the fuels consumed these days in stationary facilities at Army bases, these fuel requirements were analyzed from several points of view. The fuels consumption pattern, seasonal fuels demand,and types and fuel-firing capacities of directly fired stationary equipment were all examined. All of these characteristics have crucial bearing on the type of fuel ultimately produced from a suitable Energy Plantation for Army bases and the design of such a plantation. This analysis of fuel requirements is the subject of Appendix A.

It was known before the work was started that coal is not used in large quantities these days at major troop training centers. It was therefore obvious that considerations might have to be given either to the possibility of converting the Energy Plantation harvest to a liquid or gaseous fuel, or to the replacement of the existing heat-delivery systems in stationary facilities by central heating plants in which the plantation harvest could be burned directly as a solid fuel.

The large numbers of small heaters in use at Army bases was a surprise, and this dominant pattern of fuel usage caused much greater emphasis to be placed on means for converting the harvest from the plantation to liquid or gaseous fuel that had originally been contemplated. Consequently, a major aspect of the work reported in Appendices A and B is an evaluation of the conceivable means for making liquid or gaseous fuels from plant material. The aim of that aspect of the work was to eliminate as many of the conceivable fuel conversion means as possible by a broad general analysis.

IV.C.2.b. Seasonality of Fuel Demand at Army Bases. It was known from the beginning of the work that there is a seasonality in the demand for fuels at large Army bases, if for no other reason than the need for space heating at most localities during the winter. The range of the seasonality, however, was not known. Seasonality in heat demand is an important factor in plantation operation, because it influences the steadiness with which the work force and field equipment can be used at the plantation. The steadier the operation through the year, the better the operation will be (a full-time well-trained work force can be supported), and the lower the investment in field machinery and other equipment will be. Steadiness of operation would also be a cost benefit for any process required for converting plant material into a liquid or solid fuel.

Therefore, because only scant information is available on the seasonality of fuels demand at large Army bases, attention had to be given to devising a means for estimating that seasonality and to validating it. These steps are part of the work included in Appendix A.

IV.C.3. Consideration of Major Characteristics of Energy Plantation Fuels Production System.

IV.C.3.a. Climate and Topographic Considerations. Among the circumstances which determine the general technical practicality of Energy Plantations in particular localities are the local climate and the topography. Some of the major troop training centers are in localities having climates and topographies unsuited to growing plant material. It was necessary, therefore, to determine which of the major troop training centers are in localities suitable for plantations, and then to estimate whether those which are so located have a sufficently large total fuels demand for stationary facilities to justify pursuit of the Energy Plantation system evaluation. This analysis is part of the work discussed in Appendix B.

IV.C.3.b. Final-Fuel-Form Considerations. The plant material grown in Energy Plantations might be used as a solid fuel, after it is partially dried, or alternatively it might be converted into a gaseous or liquid fuel by a pyrolytic or biological process. The relative merits and inherent feasibilities of these possibilities are considered in terms of fuel storage, fuel yield from the plant-matter raw material, overall thermal efficiency of the fuels conversion process, and ready availability of alternate backup fuels which could be substituted without equipment modifications.

Consideration of these topics in Appendix B led to the conclusion that synthetic natural gas and solid fuel are the preferred final fuel forms for the plant material harvested from Energy Plantations suitable for supplying the fuels requirements for fixed facilities at Army bases. Consequently, detailed consideration was limited to the systems for producing and using Energy Plantation fuel in these forms.

IV.C.4. Estimation of Plant-Material Growth Rates From Deciduous Species. Few of the Army bases are in localities from which data are available on the yields of plant species specially suitable for plantation culture. Means had to be devised, therefore, for estimating yields from these species at particular bases from data collected at other, often distant, locations. In addition, the optimum sustainable yield per acre-year from a particular species is a function of planting density and harvest schedule. Means had to be devised for estimating the planting density-harvest schedule combination which leads to the optimum yield under plantation conditions for each locale involved. Developing these means, validating them, and demonstrating their use are the subject of Appendix C.

IV.C.5. Description of Plantation Operations, Equipment, Manpower, and Costs. Analysis of the field operations at plantations, specification of equipment and manpower, and definition of operating rates and costs were developed by InterTechnology's agricultural engineering and farm management consultants[9] whose experience includes large-scale farming, and range and forestry operations in the Midwest and the South. The consultant also provided information about the cost of the equipment and expected service lives, its maintenance and supply requirements, its crew requirements and pay rates.

From this information, the size and production capacity of a unit could be determined which makes full-time use of its equipment and manpower for its field operations and for transporting harvested plant material to its point of use and returning the residues to the plantation.

The costs and work programs for one of these production units, and its supervisory and maintenance requirements are expressed in general terms in Appendix F. These unit capabilities and costs can be used for plantation estimates for any Army base, and they are the basis for the approximately optimized estimates made for plantations at Forts Leonard Wood and Benning in Appendices F and G, respectively. These appendices also include sensitivity analyses with respect to operating costs, plantation area requirements, and the cost of establishing plantations.

IV.C.6. Development of Process Engineering of an Anaerobic Digestion Process for Making SNG. Synthetic natural gas has never been made on a large scale from fresh plant material. In fact, even laboratory work along these lines is quite limited. However, based on such experimental data as there are available bearing on and related to such a process, material balances and operating rates have been estimated for a proposed process scheme.

The equipment requirements for the proposed process were analyzed to determine the capacity of a processing train using equipment regularly manufactured at present. The cost of a pretreatment and digestion train having this capacity has been estimated on the basis of equipment costs from the trade and other sources. Two or more such trains could be operated in parallel to meet the SNG requirements for a particular Army installation.

There is flexibility in the capacity of the boiler plant and gas purification train in the SNG production process. It is contemplated, therefore, that several pretreatment and digestion trains would be served by a single boiler plant and purification train. The costs of these two elements of equipment have, therefore, been expressed as a function of their capacity.

Operating costs and manpower requirements have been estimated for the pretreatment and digestion train, and for the boiler plant and purification train.

The "unit" cost estimates can be used for estimating the capital and operating costs for an SNG production facility at any Army base. They are the basis for the costs estimated for Forts Leonard Wood and Benning in Appendices F and G, respectively. Detailed discussion and analysis of the proposed SNG production facility, its operation and costs are the subjects of Appendix D. The appendix also includes a sensitivity analysis of the capital and operating costs of the process as a function of several operating parameters.

IV.C.7. Definition of Facilities for Direct Combustion of Plant Material. If the plant material from the plantation is to be used as a solid fuel for supplying the heat requirements in the stationary facilities at an Army base, at least one central boiler plant and steam-distribution system will be required. It will be a replacement for the system consisting of hundreds and sometimes thousands of relatively small unattended gas or oil-fired heating units now used. The cost of such a central system will depend very much on the building layout at each base. A generalized procedure for estimating the cost of such a system, therefore, has not been worked out.

Approximate partial capital and operating costs have been estimated for Forts Benning and Leonard Wood. These costs provide for a central boiler plant and an underground steam-distribution system. They do not include the cost of changes which may be necessary in each building served, nor do they make allowance for the cost of either storing and preserving substantial quantities of harvested plant material during the summer when the demand for fuel is at its low point or, alternatively, varying the harvest rate at the plantation to conform to changes in fuel demand.

Detailed discussion of these matters is the subject of Appendix E.

IV.D. Consideration of Two Large Army Bases in Detail. Detailed evaluation of the feasibility of Energy Plantation systems have been made for Forts Benning and Leonard Wood. These evaluations illustrate application of the general procedures for assessing the feasibility of Energy Plantations developed in Appendices A, C, D, E and F. They are also specific cases for two broadly representative large troop training centers in rather different regions in the country.

At Fort Leonard Wood, the climate is typically continental--summers are hot and winters are wet and cold. About 4,800 heating degree-days are normally expected every year. While precipitation averages about forty inches every year and is fairly uniformly distributed, droughty conditions often occur for thirty days or more in July and August. Summer rains tend to be downpours and much of the water runs off. The soils contain considerable fractions of chirt and gravel and on the high ground may be poorly drained. The topography is a series of rolling uplands separated by streams running through narrow valleys.

At Fort Benning, the climate is typical of the humid southeast. Maximum daily temperatures are in the low nineties on most days in June, July and August. There are frosts in winter, but freezing temperatures occur for only a day or two in most years. About 2,400 heating degree-days per year are normally expected. Rainfall averages about fifty inches per year and varies through the year, being heaviest in March and July and lightest in September and October. Three principal soil types are found in the region. Sandy soils which account for about half the area at the forts are of limited productivity, sandy loams (about twenty-five percent of the area) are productive and the Ochlocknee soils (about thirty percent of the area) are the most productive. The topography is rolling to moderately hilly uplands separated by meandering streams in fairly broad valleys.

IV.E. Limitations Imposed by Available Data. The major elements of quantitative data required for assessing the feasibility of Energy Plantation Systems for Army bases are shown in Table III. Also shown in the table are estimates of the sufficiency of the data available and estimated effects of any deficiencies in the data on the reliability of the conclusions reached in the work.

The necessary data, with respect to Army bases themselves, are either generally adequate, or means have been devised for circumventing any deficiencies.

The data on plant growth rates are on the meager side, in detail, but adequate for establishing general relationships and reasonably reliable overall estimates of plantation yields and operating requirements. The data are not sufficient for making specific species recommendations for particular plantation sites. This deficiency is the reason for recommendations C.2.a, b and d. Moreover, the fast-growing deciduous species for which data are available are species selected for study and evaluation by the pulp and paper industry, because they yield light-colored or easily bleached fiber suitable for papermaking. Neither of these criteria is important for Energy Plantation purposes. Consequently, it is possible and even likely that species more satisfactory may exist for Energy Plantation purposes. This likelihood is the basis for recommendation C.2.c. The unit cost data used for estimating the capital and operating cost in plantations are believed to be reasonably reliable as of the end of 1974.

Precise data of the kinds required for making the process design for the pretreatment and digestion stages of the SNG production process are not available. It was necessary, therefore, to estimate the data required from data for related systems and from general understanding of fermentation technology. It is believed that the estimated yield of methane per pound of dry plant matter digested is perhaps as much as twenty percent too low in light of an opinion received recently[10]. This possibly higher yield is reflected in the sensitivity analysis reported in Appendix D. The other operating parameter estimates are also subject to error, but the sensitivity analyses show that the process engineering estimates are notably less influenced by the values chosen for them than for the methane yield-per-pound of plant material digested. The unavailability of process engineering data for producing methane by anaerobic fermentation of plant material is the basis for recommendation C.1.

The unit cost data used for estimating the capital and operating costs of the SNG production process are believed to be reliable as of the end of 1974. The ranges in which the total capital and operating costs are likely to lie as determined from the sensitivity analyses shown in Appendix D are believed to be reasonably reliable.

The process engineering and cost data used for estimating the capital and operating costs for central heating plants and distribution systems for a system in which plant material from plantations is burned as a solid fuel are reasonable engineering approximations. Estimates of the costs of alterations to the heating systems inside buildings and of certain other matters have not been made because these costs are believed to be relatively small.

TABLE III

LIMITATIONS IMPOSED BY AVAILABLE DATA

Data Element	Sufficiency of the Data	Effect of Deficiencies in the Data
Fuels Consumption at Army Bases:		
-total annual consumption	Adequate	No serious deficiencies.
-consumption by fuel type	Generally adequate	Lack of data on LPG use makes estimation of cost of additional SNG distribution network impossible.
-seasonality in consumption	Inadequate	Estimation method in Appendix A probably overcomes inadequacy.
Directly Fired Equipment at Army Bases:	Adequate	No deficiencies.
Deciduous-Species-Plant-Matter Growth Rates:		
-comparative data between species at a site	Very limited	Specific species selection for a given site often impossible
-comparative yields for a species at various sites	Few data available	Uncertainty in effect of soil type, climate and insolation rate on plant-matter yield from species but not serious for general estimates of effects.
-harvestable yield per acre-year from stands at known age and planting density:		
• first harvests from stands	Several excellent data sets available	Data are adequate for defining relationships in general terms for planning purposes.
• second and subsequent harvests	A few excellent data sets available	Data are adequate for defining general relationships for planning purposes.
-fraction of plants surviving to harvest	Adequate	Generalized relationships believed reliable for planning purposes have been formulated.

TABLE III
(continued)

LIMITATIONS IMPOSED BY AVAILABLE DATA

Data Element	Sufficiency of the Data	Effect of Deficiencies in the Data
-effect of cultivation	Adequate	No deficiencies.
-effect of fertilization	Mixed, but adequate	Emphasis is on maintaining site fertility, not fertilizing specific plantings-data are adequate
-Entire body of data viewed as a whole	Fairly adequate	Estimates of harvestable yields at specific sites believed reliable to within about ±10%, but yields for specific species probably are not quite as reliable.
Warm-season Grass Plant-Matter Growth Rates	Data are reasonably adequate.	No serious problems-in any event, only a few localities are suitable for warm-season grasses.
Plantation Operation Cost Data	Unit data (equipment costs & capacities are good.	Estimated plantation capital costs and plant-matter production costs are sufficiently reliable for purposes of the work.
SNG Production Process	Essentially no precise design data are available, "reasonable" estimates have been used, capital and operating cost factors are fairly reliable.	Methane yield estimates probably on low side, hence SNG costs and process plant capital cost probably about 15 and 25 percent high, respectively--other operating parameter estimates are less critical.
Solid Fuel Systems for forts Benning and Leonard Wood	Process engineering and capital and operating costs for central heating plants and distribution systems are good engineering approximations.	Cost estimates do not include costs for alterations within buildings and fuels storage or seasonal harvesting--hence total costs for entire systems will be higher than estimates.

V. FUELS CONSUMPTION IN STATIONARY FACILITIES AT MAJOR TROOP TRAINING CENTERS

V.A. Summary. At nearly all large troop training centers in unurbanized localities in the contiguous forty-eight states, more than half (and frequently much more than half) of the heat generated in stationary facilities from fuels is consumed in small isolated unattended space and hot-water heaters (firing capacity less than 750,000 Btu per hour) and in intermediate heaters (firing capacity between 750,000 and 3.5 million Btu per hour) which are also usually isolated and unattended. Fuel use in central boiler and heating plants at bases in the lower forty-eight states generally accounts for less than half the total fuels consumption at each base. At many large bases, there are more than a thousand small heaters, less than a hundred intermediate heaters and fewer than ten central boiler and heating plants.

Neither coal nor any other solid fuel is used these days in substantial quantity in any of the larger troop training centers in the contiguous forty-eight states. Gas is the major source of heat at bases in the South and in many localities in the Midwest. Oil is more likely to be the major source of heat at bases in the North and Northwest.

These characteristics of directly fired equipment and the widespread use of gas and oil at stationary facilities at large troop training centers indicate that, if Energy Plantations are to be a major source of fuel for the fixed facilities at the centers,

- either a substantial part of the fuel derived from the plantations must be suitable for use in unattended small-capacity heaters,
- or the many small and intermediate-capacity heaters will have to be replaced by central heating systems where the product of the plantations can be burned satisfactorily as a solid fuel.

Heat loads in winter months vary from about twice the baseload during the summer at troop centers in the South to about five times the summer load at centers in the North. This variation has important implications for Energy Plantation systems at Army bases. If the fuel production rate from plantation systems cannot be made to follow the seasonal demand for heat, the fuel produced in periods of low heat demand must be conveniently storable for use when the demand for heat is high.

The heating equipment and fuels used at Forts Benning and Leonard Wood are broadly representative of the equipment and fuels consumption pattern at bases in the South and in more northerly localities, respectively.

A more thorough discussion of the pattern of fuels consumption in stationary facilities at Army bases is the subject of Appendix A.

V.B. Types and Capacities of Direct-Fired Equipment. Directly fired heating equipment at Army bases is segregated by the Army[1] into four general classes of equipment as follows:

- high-pressure boilers having firing rates of 3.5 million Btu per hour or greater, used for generating saturated steam at 135 psia or higher or, in a few instances, superheated steam at higher pressures, and for generating high-temperature water--these boilers are usually located in boiler plants with operators in attendance and may be modern units equipped for firing oil or gas, but some are older, formerly coal-fired units which have been refitted for oil or gas;
- large heaters having firing rates of 3.5 million Btu per hour or greater, used for producing hot water at lower temperatures than in high-pressure boilers or, in some instances, for

generating steam at lower pressures than in high-pressure boilers--these units may be isolated or in central plants, and they may be attended or unattended--they may be modern units designed for oil or gas firing, or may be older units originally designed for coal but later refitted for oil or gas;

- intermediate heaters having firing rates between about 750,000 and 3.5 million Btu per hour used for water heating, low-pressure steam, and space heaters--these units are usually isolated, often unattended and generally fired with gas or oil; and
- small heaters having firing rates below about 750,000 Btu per hour used for hot water or space heating--nearly all these units are isolated, unattended and fired with oil or gas.

Cooking stoves represent another substantial source of fuel demand. Some of these units may be oil fired, but most of them use gas.

The relative amounts of fuel consumed in high-pressure boilers and heaters vary widely among Army installations. This point is illustrated in Table IV where fuel consumptions in high-pressure boilers and in each of the three classes of heaters are expressed as percentages of total fuel energy used in fiscal year 1971 at a number of the largest Army installations. The installations are arranged in the order of increasing normally expected heating degree-days per annum at their respective localities. The information shown in Table IV is believed to include fuel used in cooking stoves.

The information for the Army installations shown in Table IV indicates that for fiscal year 1971:

- small heaters used very large fractions of the fuels consumed in fixed facilities at all the Army installations other than the three in Alaska and were, in fact, the largest

TABLE IV

CONSUMPTION OF ENERGY FROM FUELS IN FISCAL YEAR 1971 AT SELECTED ARMY INSTALLATIONS BY CLASS AND CAPACITY OF DIRECTLY FIRED EQUIPMENT

Installation	Estimated Normal Degree-Days Per Year	Total Fuels Consumption Billion Btu	Percent of Total Fuels Consumption			
			High-Pressure Boilers	Large Heaters	Intermediate Heaters	Small Heaters
Fort Polk, La.	1,900	1,578	8	<1	<1	91
Fort Hood, Texas	2,000	1,623	7	8	8	76
Fort Stewart, Ga.	2,000	623	35	3	18	44
FORT BENNING, GA.	2,400	2,387	41	1	2	56
Fort Gordon, Ga.	2,500	1,524	49	-	9	42
Fort Jackson, S.C.	2,600	1,387	49	1	4	46
Fort Bliss, Texas	2,700	1,589	8	11	10	71
Fort McClellan, Ala.	2,900	518	34	4	11	51
Fort Bragg, N.C.	3,100	2,772	42	<1	13	44
Fort Sill, Okla.	3,100	1,602	11	13	20	56
Fort Huachuca, Ariz.	3,700	493	29	11	8	52
Fort Campbell, Ky.	3,800	1,580	46	1	1	52
Fort Knox, Ky.	4,600	3,073	20	4	18	58
FORT LEONARD WOOD, MO.	4,800	2,165	26	1	10	63
Fort Dix, N.J.	5,000	2,382	50	7	7	36
Fort Riley, Kans.	5,100	1,993	13	11	11	65

TABLE IV

(continued)

CONSUMPTION OF ENERGY FROM FUELS IN FISCAL YEAR 1971 AT

SELECTED ARMY INSTALLATIONS BY CLASS AND CAPACITY OF DIRECTLY FIRED EQUIPMENT

Installation	Estimated Normal Degree-Days Per Year	Total Fuels Consumption Billion Btu	Percent of Total Fuels Consumption			
			High-Pressure Boilers	Large Heaters	Intermediate Heaters	Small Heaters
Fort Lewis, Wash.	5,500	2,327	45	2	12	41
Fort Carson, Colo.	6,500	1,851	22	2	14	62
Camp Drum, N.Y.	7,400	314	6	19	29	46
Fort Greely, Alaska	9,000	212	80	4	4	12
Fort Richardson, Alaska	9,000	1,714	88	5	2	6
Fort Wainwright, Alaska	9,000	2,124	95	3	1	2

Source: Reference 2, except the data in the second column from the left, which is based on information from reference 6.

single class of consumers in fifteen of the nineteen installations located in the forty-eight contiguous states;

- intermediate heaters in most instances (eighteen out of the nineteen installations in the lower forty-eight states) accounted for twenty percent or less of the total fuels consumed in fixed facilities, the sum of the fuels consumed in small and intermediate heaters accounting for more than fifty percent (and frequently very much more) in eighteen of the nineteen installations in the lower forty-eight states;
- in seven instances, high-pressure boilers were the largest single class of consumers, although only four of these instances were among the nineteen installations in the lower forty-eight states, and except for the Alaskan installations, fuels use in high-pressure boilers was not greater than half the total fuels used in any of the nineteen installations in the contiguous states, and
- large heaters consumed only a relatively small fraction of the total fuels consumed at any of the installations--in fact, less than nine percent in seventeen of the twenty-two installations shown in the table.

No relationships are discernible between the fraction of the fuels consumed in high-pressure boilers or in any class of heater on the one hand, and either total fuels consumption at individual installations or the normally expected heating degree-days per year at the installations on the other hand.

The limited data available[1] for fiscal year 1973 for installations included in Table IV indicate approximately the same fuels-consumption distribution between high-pressure boilers and heaters as in 1971, thus confirming that intermediate and small heaters are the major consumers of fuel at most large Army bases.

The preeminence of small and intermediate-capacity heaters as consumers of fuels at the larger Army installations in unurbanized localities is reflected by their number relative to the number of large-capacity heaters and high-pressure boilers in use. A "census" of various classes and capacities of directly fired equipment at a representative list of troop training centers is shown in Table V. The overwhelming numbers of small and intermediate-capacity heaters is a significant factor bearing on the selection of the most appropriate type of Energy Plantation system to be recommended for serving Army installations.

It is evident from this analysis, that if Energy Plantations are to be a major source of fuel for fixed facilities at large troop training centers, either a substantial part of the fuel derived from the plantations must be suitable for firing in unattended equipment having a fuel capacity less than 750 thousand Btu per hour, or alternatively, this small-capacity equipment will have to be replaced by central heating systems in which the fuel derived from the plantations can be burned satisfactorily.

High-pressure boilers are often the second-largest total consumer of fuels in fixed facilities at Army training bases in unurbanized localities. However, their consumption is usually a considerably smaller part of the total fuel consumed than is in small and intermediate heaters. Therefore, if fuel derived from Energy Plantations is tailored specifically to meet the requirements of high-pressure boilers, and if this tailoring makes the fuel unsuitable for small and intermediate-capacity heaters, Energy Plantations cannot be a major fuels source for large troop training centers as they are now equipped for meeting space and water-heating requirements. On the other hand, if the fuel derived from Energy Plantations is suitable for use in small and intermediate-capacity heaters and also in high-pressure boilers, Energy Plantations could provide essentially all the fuel used in the fixed facilities at training bases.

V.C. Demand by Fuel Type. Coal is not used these days in substantial quantities at troop training centers in the contiguous forty-eight states[1]. Gas is the major source of heat at installations in the South and in many localities in the Midwest, and oil is more likely to be so at posts in the North[1]. This point is illustrated by data compiled for a recent period by the Defense Energy Information System (see Table VII).

Fuels consumption for fixed facilities at Fort Benning in Federal fiscal year 1973 conformed completely to these general conclusions (see Table VII). At Fort Leonard Wood, however, oil accounted for about sixty-nine percent of the heat produced in 1973, gas accounting for substantially all the remainder (see Table VIII). Coal is not an important factor at Fort Leonard Wood or Fort Benning.

V.D. Seasonality of Fuels Demand at Army Bases. The seasonal variation in heating load is an influential factor in the performance requirements of Energy Plantations and their associated fuels-processing systems designed for supplying fuel for fixed facilities at troop training centers. Few data have been compiled, however, on the changes in heating load through the year at major troop bases in unurbanized localities. There are no seasonal data, for instance, for Fort Benning or Fort Leonard Wood, but partial data are available for Forts Bragg, Meade and Belvoir[3]. No seasonal data are known to exist for any other large troop center[4,5].

The partial data available for the three bases named in the preceding paragraph are for groups of high-pressure boilers which are generally operated all year. The data for Fort Bragg are for four such boilers which consumed about twenty-four percent of all the fuels (expressed as Btu as fired) used at the base in Federal fiscal year 1973.

TABLE V

NUMBERS AND FIRING CAPACITY OF DIRECT-FIRED EQUIPMENT AT A REPRESENTATIVE LIST OF TROOP TRAINING CENTERS

Installation	Total Direct-Fired Units	Number of High-Pressure Boilers	Numbers of Heaters by Firing Capacity, Million Btu per Hour		
			>3.5	3.5-0.75	<0.75
Fort Bragg, N. C.	6,213	9	13	99	6,092
Fort Campbell, Ky.	2,776	31	2	88	2,655
Fort Knox, Ky.	1,503	22	34	145	1,302
FORT LEONARD WOOD, MO.	1,545	6	9	56	1,474
Fort Riley, Kans.	1,055	4	65	346	640
Fort Carson, Colo.	2,538	4	39	82	2,413

Source: Reference 1.

The shapes of the heating-load profiles through the year reported for high-pressure boilers at Forts Bragg, Meade and Belvoir are quite similar. During the warmer months, there is a base load which is about a third of the general load level in the colder months. The base load in the warm season is represented primarily by mess hall and hot-water needs. The difference between the loads in the warm and cold seasons is the space-heating requirement in wintertime. The loads in each of these major seasons are remarkably uniform, and the seasons are separated by approximately one-month periods during which the load level is intermediate between the two major seasonal loads. The seasonal heat-load profile for the four high-pressure boilers at Fort Bragg for which seasonal data are available as a group is shown by the dotted line in Figure I. These heat-load data were provided by Von Nida[3]. Comparable graphical presentations for Forts Meade and Belvoir are included in reference 1.

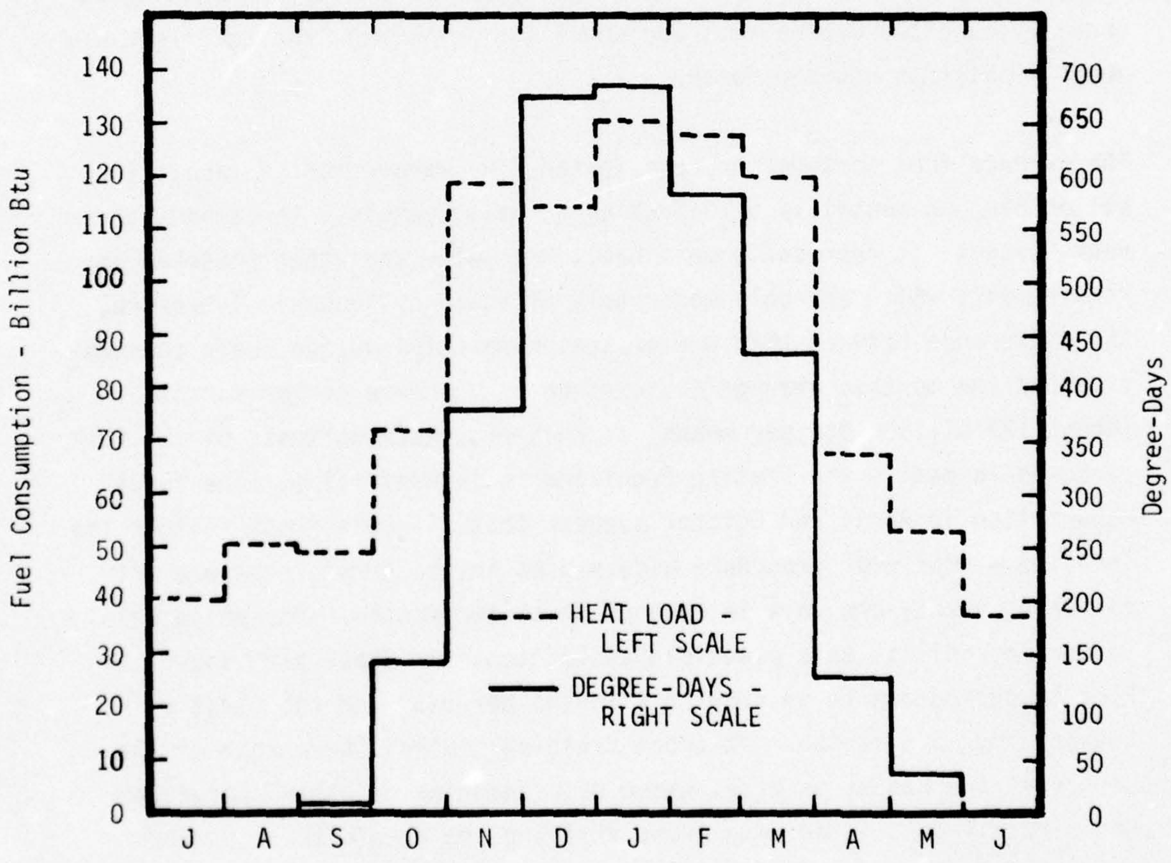
Because of the similarity between the seasonal heat-load profiles at Forts Bragg, Meade and Belvoir[1], and because Fort Bragg is a good candidate for an Energy Plantation--unurbanized location, large land area and fuel consumption of the order of three trillion Btu per year in fixed facilities--it has been decided to use the Bragg data as the basis for estimating seasonal heating loads at other large training centers in unurbanized localities[4]. Centers in the more heavily urbanized localities, such as is the case for Forts Meade and Belvoir, frequently do not have land areas adequately large on site or nearby for Energy Plantations with a potential fuels production capacity comparable with the fuels demand of the fixed facilities at the centers.

The heat loads by months for Federal fiscal year 1973 for the group of four high-pressure boilers at Fort Bragg are compared in Figure I with the estimated normally expected heating degree-days, also by months, in the vicinity of the base. The degree-day data are for Fayetteville, North Carolina, the meteorological station nearest to Fort Bragg. It

FIGURE I

FUEL CONSUMPTION PROFILE FOR FOUR HIGH-PRESSURE BOILERS
AND ESTIMATED NORMAL DEGREE-DAYS COMPARED

FORT BRAGG - FEDERAL FISCAL 1973



Sources: Heating degree-days - reference 6.
Heat-load data - reference 3.

will be seen that in the five months when the normally expected degree-days are fewer than fifty, the heat load ranges from slightly less than 40 to slightly over 50 billion Btu per month. The average heat load during this warm season was about 46 billion Btu per month.

In the five-month period during which estimated normally expected degree-days exceed three hundred per month, the heat load varied from about 110 to about 130 billion Btu per month. The load averaged about 123 billion Btu per month during this period. In October and April, when estimated normally expected degree-days are about 135 per month, the heat load was about 70 billion Btu per month.

The average fuel consumption rate in the five warmer months (about 46 bilion Btu per month) is a load which actually persists throughout the year, because it represents mess hall, hot water and other housekeeping requirements which are only moderately affected by season. Therefore, the difference between this warmer-season-monthly-average fuels consumption and the monthly average consumption in the five cooler months (about 123 billion Btu per month) is an approximate estimate of the fuel consumed to meet space-heating requirements in wintertime. The fuels consumption in April and October suggest that, if Fort Bragg follows the "heat on - heat off" procedure widely used in the Army[1], heat was off for about twenty-one days in each of these two months. Accepting this latter possibility as a plausible assumption, the "heat off" season at Fort Bragg appears to be about 6.5 months per year and the "heat on" season about 5.5 months. At troop training centers where most of the personnel are housed on base, where manufacturing or other operations not directly associated with troop training are about "average" for bases primarily devoted to troop training, and where consumption of

TABLE V

FUELS CONSUMPTION BY FUEL TYPE
AS A FUNCTION OF LOCATION FOR REPRESENTATIVE ARMY INSTALLATIONS

Installation and Location	Estimated Normal Degree-Days Per Year	Fuel Consumption - Billion Btu				Distribution of Fuel Consumptio[n] Percent of Total Consumption		
		Total	Gas	Oil	Coal	Gas	Oil	Coal
Fort Hood, Texas	2,000	1,700	1,698	1	--	99+	1	--
FORT BENNING, GA.	2,400	2,073	1,893	179	--	91	9	--
Fort Bragg, N. C.	3,100	3,013	2,032	957	25	67	32	1
Fort Knox, Ky.	4,600	2,950	2,482	390	79	84	13	3
Fort Lewis, Wash.	5,500	2,494	124	2,370	--	5	95	--

Source: Defense Energy Information Service as per reference 1.

electricity generated outside the base is also about "average" for troop training centers, it would be expected that fuels consumption in fixed facilities:

- for purposes other than space heating will vary more or less directly with the scale of operations at the center, and
- for space-heating purposes will vary with the scale of operations and with the severity of winter at the center.

If these premises are accepted, and if it is also assumed that:

- the seasonal pattern of fuels consumption in the four high-pressure boilers for which seasonal fuels-use data are available for Fort Bragg is essentially the same as the seasonal pattern for total fuels consumption in fixed facilities at Fort Bragg, and that
- operations at Fort Bragg are similar in all respects, except possibly for scale, to operations generally in troop training centers,

then the fractional distribution of fuels consumption in fixed facilities at training centers for base-load purposes (mess halls, water heating and other housekeeping purposes which are not notably affected by season) and for space heating can be estimated on the basis of an index characteristic of the climate at the base and the total yearly fuel consumption at the base. A detailed discussion of the method is given in Appendix A, Section V. The validity of the method and its general applicability to troop training centers has been tested by estimating the overall space-heating requirement per square foot of enclosed floor area per normally

TABLE VII

FUELS CONSUMPTION IN FEDERAL FISCAL YEAR 1973
FOR FIXED FACILITIES AT FORT BENNING

	Fuels Consumption - Billion Btu		
Direct-Fired Equipment Type	Gas	Oil	Coal
High-Pressure Boilers:	1,235	--	--
Large Heaters:	34	--	--
Intermediate Heaters:	36	5	--
Small Heaters:	993	199	12
Totals:	2,298	204	12
Grand Total:		2,514	
Percent of Grand Total:	91	8	<1

Sources: References 3 and 4.

expected heating degree-day per year for each of the Army installations listed in Table IV. For convenience, this ratio is referred to as the space-heating loss coefficient. Because of the general similarity of building construction at Army bases, it would be expected that the estimates of the space-heating loss coefficient for all installations would tend to be about the same. Since such has been found to be the case (see Table A-X in Appendix A), for the majority of the bases listed in Table IV, the seasonal-heat-load estimation method is approximately valid.

The seasonal-heat-load estimation method has been used for estimating the total heat load by months for Forts Benning and Leonard Wood. The estimates (see Table IX) show, as is to be expected, that fuels consumption at Forts Benning and Leonard Wood peak in January. The peak demand for space heating throughout the country generally occurs in that month. For Army installations, the magnitude of the peak in relation to the year-long base fuels demand for mess halls, water heating and other housekeeping requirements which are not seasonally affected depends on the severity of winter at each particular Army installation. This point is illustrated in Table X, where in the eighth column, estimates are shown of the ratio between the fuels requirements in summer months (the fifth column in the table) and normally expected total fuels demand for fixed facilities in the coldest month of the year (the seventh column). It will be seen that this ratio varies from about two to nearly six for the range of winter severities (heating degree-days per year) shown in the table.

The wide seasonal variation in heating load at Army bases throughout the country has important implications for Energy Plantation systems at bases. If the fuels production rate from plantation systems cannot be made to follow the seasonal changes in heat load, the fuel produced from the systems when the heat load is low must be conveniently storable for use when the demand for heat is high.

TABLE VIII

FUELS CONSUMPTION IN FEDERAL FISCAL YEAR 1973 FOR FIXED FACILITIES AT FORT LEONARD WOOD

	Fuels Consumption - Billion Btu		
Direct-Fired Equipment Type	Gas	Oil	Coal
High-Pressure Boilers:	77	557	14
Large Heaters:	9	22	--
Intermediate Heaters:	26	153	--
Small Heaters:	525	696	--
Totals:	637	1,428	14
Grand Total:		2,079	
Percent of Grand Total:	31	69	<1

Sources: References 3 and 4.

TABLE IX

ESTIMATED AVERAGE FUELS CONSUMPTION PROFILES FOR FIXED FACILITIES AT FORTS BENNING AND LEONARD WOOD

Billions of Btu

Month	Fort Benning			Fort Leonard Wood		
	Base Load	Space Heating	Total	Base Load	Space Heating	Total
July	131	-	131	79	-	79
August	131	-	131	79	-	79
September	131	-	131	79	-	79
October	132	42	174	79	51	130
November	131	125	256	79	151	230
December	131	208	339	79	235	314
January	132	221	353	80	260	340
February	131	174	305	79	207	286
March	131	126	257	79	174	253
April	131	43	174	79	52	131
May	132	-	132	79	-	79
June	131	-	131	79	-	79
Totals	1,575	939	2,514	949	1,130	2,079

Assumptions:	Fort Benning	Fort Leonard Wood
Heating degree-days per year	2,400	4,800
Duration of "heating season"-months	5.5	5.5
Total fuels consumption-Billion Btu	2,514	2,079

TABLE X

SUMMARY OF EFFECT OF SEASONAL CLIMATE FACTORS ON FUELS DEMAND FOR FIXED FACILITIES AT ARMY INSTALLATIONS IN UNURBANIZED LOCALITIES

Heating Degree-Days Per Year	Approximate Duration of Heating Season Months per Year	Btu Per 1,000 Btu of Fuel Consumed Per Year					Ratio: Total Btu in Coldest Month to Base Load
		Base Load*	Space Heating	Base Load* Per Month	Space-Heating Load-Coldest Month	Total Btu in Coldest Month	
1,000	3.5	801	199	67	56	123	1.8
2,000	4.5	668	332	56	89	145	2.6
3,000	5.5	573	427	48	94	142	3.0
4,000	5.5	502	498	42	110	152	3.6
5,000	6.5	446	554	37	116	153	4.1
6,000	7.5	402	598	33	120	153	4.6
7,000	8.0	365	635	30	121	151	5.0
8,000	8.0	335	665	28	126	154	5.5
9,000	8.5	310	690	26	124	150	5.8

Sources:

Second column: based on data in Table 321 in the 1974 edition of the Statistical Abstract of the United States -- U. S. Department of Commerce.

Third and Fourth columns: derived from the estimates in the second, third and fourth columns of Table A-XII., Appendix A.

Fifth column: the third column divided by twelve.

Sixth column: based on data in the reference for the second column and the estimates in the fourth column.

Seventh column: the sum of the estimates in column five and six.

Eighth column: estimates in the seventh column divided by estimates in the fifth.

*Base Load: Mess halls, water heating and other housekeeping purposes which are not notably affected by season.

VI. MAJOR CHARACTERISTICS OF ENERGY PLANTATIONS AND FINAL-FUEL-FORM CONSIDERATIONS

VI.A. Summary. After allowance for climate, topography and population density, Energy Plantations are considered a practical possibility for large Army installations in unurbanized localities in the region approximately defined by the eastern and central time zones, but excluding the Appalachian Mountain region and the densely populated corridor extending along the Atlantic coast from northern Virginia to New Hampshire. There are also a few technically suitable localities in California and eastern Washington, but the major part of the mountain and Pacific time zones is not suitable. Alaska is generally unsuitable for Energy Plantations. Forts Benning and Leonard Wood are in suitable localities, although their localities are not the most suitable.

The most widely suitable plant species for Energy Plantation culture are certain selected deciduous tree species grown in dense plantings (5,000 to 11,000 plants per acre) and harvested first when the stand is one or two years old, and then five to seven more times at two to three-year intervals thereafter. These species not only resprout vigorously from their stumps, but can be started readily from live cuttings. At least one of this group of species is known to grow well under plantation conditions in essentially every location of practical interest to the Department of Defense for Energy Plantation systems. Sustained annual yields from these species have been shown to be between seven and ten dry tons of harvestable material per acre per year.

Certain perennial warm-season grasses are also promising candidates for localities in Florida and near the coast of the Gulf of Mexico. Their yields in managed plantings have been shown to be comparable with those from the selected group of deciduous species.

No annual plant is satisfactory for plantation culture.

The plant material grown in Energy Plantations might be used as a solid fuel after partially drying it. Alternatively, it might be converted to a gaseous or liquid fuel by pyrolytic or biological processes. Analysis of the relative merits and practical feasibilities of these various processes leads to the conclusion that using the harvest from the plantation either directly as a solid fuel or converting it by anaerobic fermentation to synthetic natural gas are the only two final fuel forms worthy of thorough consideration.

VI.B. Climate and Topographical Considerations.

VI.B.1. Precipitation. All plant species require a considerable amount of water to support their growth and survival. The amount of water required varies among species from somewhat less than two hundred to somewhat more than four hundred pounds of water per pound of oven-dry plant matter produced[7]. No plant species of interest for Energy Plantation culture requiring less than about two hundred pounds have been identified. In fact, many of the species of most interest require nearer three hundred than two hundred pounds per pound of harvestable, oven-dry plant matter produced. Moreover, to be of practical interest, a combination of plantation site and species must produce at least seven tons, and preferably nearer ten tons, of harvestable, oven-dry plant material per year (see particularly appendices F and G).

The combined effect of the water and harvest-yield requirements on Energy Plantation operation means that practical plantations cannot be established in territories where precipitation is normally less than about twenty inches per year.

In the contiguous forty-eight states, precipitation is generally at least twenty inches per year in the territory east of about the 101st meridian and on the western slopes of the mountains along the Pacific coast. The land between these two regions, except for the western part of Idaho and eastern Washington, normally experiences less than twenty inches of precipitation per year and is, therefore, generally too arid for worthwhile Energy Plantation operations.

In Alaska, while precipitation is heavy in the coastal region east and south of the Aleutian Island chain, it is relatively low in most other parts of the state. For example, in the vicinities of Anchorage, Bethel and Fairbanks, normal precipitation is twenty inches or less per year.

VI.B.2. Hilliness and Elevation. The steepness of slopes in the terrain is another factor which influences the practicality of Energy Plantations. Generally speaking, the field machinery required for plantation operation cannot be used effectively on slopes whose steepness exceeds about twenty-five percent (fifteen degrees). The elevation of the terrain is also a factor which must be considered. As elevation increases, productivity of land in terms of its ability to support plant growth generally declines, and at elevations over about 3,000 feet above sea level, productivity will be below that required for Energy Plantation operation. Steep hilliness or high elevation rule from consideration for Energy Plantations most of the land on the western slopes along the Pacific coast, nearly all the land with more than twenty inches of precipitation per year in Idaho and much of that in eastern Washington, and the land in the Appalachian Mountain region in the east.

VI.B.3. Growth Rates. The rate at which plants grow, assuming the water and fertilizer supply and soil depth are not limiting factors, is dependent on the length of the growing season, and on the hours of sunshine per day and ambient temperatures during the growing season. These factors are not expected to be a serious limitation on the feasibility of Energy Plantations in those regions in the contiguous forty-eight states where precipitation, hillines and altitude are within the acceptable bounds already described. Plant-material growth rates in Alaska are too low for satisfactory plantation performance.

IV.B.4. Population Density. While neither a climatic nor a topographic factor, it is convenient at this juncture to consider the possible effect of high population density in the environs of Army installations on the feasibility of establishing Energy Plantations at or in the vicinities of the installations. High population density in the general locale of a base would not necessarily be a consideration if sufficient land can be made available on the base itself for an Energy Plantation of suitable size. However, if enough land is not available on site, it may not be feasible to assemble sufficient nearby land off-site to meet the needs of an Energy Plantation for a base in a densely populated region. Consequently, those localities where population density exceeds three hundred persons per square mile have been eliminated from possible consideration for Energy Plantation sites. The effect of this exclusion is to preclude army installations to the east of the Appalachians from New Hampshire to northern Virginia, and in about fifty other widely separated localities to the east of the Rocky Mountains from consideration for Energy Plantations.

VI.B.5. Regions Suitable for Energy Plantations. It is concluded after allowance for climate, topographic and population-density considerations, that Energy Plantations can reasonably be considered for major troop training centers and other large installations operated by the Army in unurbanized localities almost anywhere in the eastern and central time zones, except for the Appalachian mountain area and the densely populated corridor extending along the Atlantic seaboard from northern Virginia to

New Hampshire (see map in Figure B-I in Appendix B). Limited precipitation, adverse topography or high population density preclude most of the territory in the mountain and Pacific time zones from consideration. The local climate makes Army installations in Alaska unattractive possibilities for Energy Plantations.

In the light of these conclusions, fifteen of the twenty-two Army installations shown in Table I are in localities technically suitable for consideration for Energy Plantations. The reasons for eliminating the others are summarized in the table. Forts Benning and Leonard Wood are among the technically suitable sites, although they are not the most suitable of those shown in the table.

VI.C. Plant Species for Energy Plantation Culture. Previous work[8] has indicated that the species grown in Energy Plantations must be perennials, so that harvesting can take place continuously throughout the year in response to the demand for solid fuel or for raw material from which to make synthetic natural gas by anaerobic fermentation. The importance of limiting consideration to perennial species is not dependent, however, only on the demand for solid fuel or raw material for synthetic natural gas.

VI.C.1. Annuals are Unsuitable. If annual species were produced in the plantation, they would, in all probability, have to be started in a short interval in the spring and be harvested, also in a short interval, in the fall while they are still upright and relatively easy to reap. In any event, they would have to have been completely harvested by the time the land must be prepared in the spring for the next planting. Under such a seeding and harvesting schedule, most of the plantation machinery and manpower would be in use for only a few weeks every year.

Moreover, storing harvested plant matter from annuals for use between harvests would be a horrendous problem. Green plant matter gradually develops considerable biological activity beginning within a few days after it is harvested and lasting for at least several weeks if steps are not taken to arrest the activity. The biological activity reduces the fuel value of the plant material as a solid fuel and as a raw material for SNG production. The activity can be arrested by drying the plant matter to an air-dry condition shortly after harvesting. It can also be controlled with bactericides and other preservatives. Air-drying could be relatively costly and might require considerable fuel (cf. the fuel needs for crop-drying in the small-cereals and corn belts, for instance). Reliance on bactericides and the like would not only be costly, but their presence in the plant matter would interfere with its subsequent use for SNG production by anaerobic fermentation.

The preservation of perennial plant material is far simpler. Nature preserves it until it is harvested as long as the plant is alive, and it can be reaped more or less continuously throughout the year only a few days, and certainly not more than a week or two, before it is needed as fuel or as raw material for SNG.

VI.C.2. Certain Perennials are Suitable. Not all perennials are equally suitable for SNG production, although there are fewer limitations on species suitable for solid fuel. Lignin, for example, is not converted to methane by anaerobic digestion. Therefore, species having relatively low lignin contents, such as grasses and deciduous tree species, are to be preferred over conifers if SNG is to be made from the plant material.

Moreover, sapwood in woody species appears to react more rapidly in biological systems than does heartwood. As a consequence, if a woody species is to be the source of plant matter for methane production, a species which grows rapidly in its first few years before it has a chance to develop much heartwood is to be preferred over one which grows more slowly. Certain deciduous species have this trait. Conifers generally do not. Rapid juvenile growth is also an important advantage if plant material is to be used as a solid fuel.

A substantial number of deciduous species, especially when they are not more than four or five years old, will sprout vigorously from their stumps after their structure above ground has been harvested. It is a matter of established fact that many deciduous species can be harvested at least five or six times before the vigor with which they regrow begins to wane. Since planting costs are a substantial part of the costs of producing any plant matter, those deciduous species which sprout readily after harvesting and, hence, provide several crops per planting have an advantage over other species which do not. Conifers rarely sprout after they have been cut down, which is another reason why certain deciduous species are to be preferred over conifers as a source of plant matter for SNG production or solid fuel.

Deciduous species which grow rapidly when they are young and sprout vigorously from their stumps after harvesting usually can also be started vegetatively from clones. A clone is a live stick four to twenty inches long (the length depends on the species) cut from a living plant. If the clone is stored in a moist condition in a cool place (between thirty-five and forty degrees Fahrenheit) for two or three months and then is stuck in the ground, it will start growing rapidly soon thereafter. This is another trait not shared by conifers. The advantages of vegetative reproduction over reproduction from seeds for Energy Plantation culture are:

- it is far easier and cheaper to collect clones than seeds from tree species; and
- clones reproduce a plant genetically identical with the one from which they were cut, whereas seeds may not.

Fortunately, there are a number of well-known deciduous tree species which reproduce vegetatively, resprout copiously from their stumps several times without loss of vigor, grow relatively rapidly when they are young, and develop little heartwood until their structure above ground is four or five years old. Some of these species are hybrids developed for propagation in a wide variety of soil types and climates. Others are natural species which adapt themselves fairly readily to a range of soils and climates. A representative list of these species and where they have grown well under plantation-type conditions is shown in Table XI. It is apparent from the table that there is at least one deciduous species which is known to grow well under plantation-type conditions for essentially every location in the lower forty-eight states where establishing Energy Plantations may be of interest to the Department of Defense.

VI.C.3. Sustained Yields from Deciduous Species. The average yield per year per acre which can be produced from deciduous species of the types shown in Table XI in localities to which they are well suited, depends on the number of plants per acre and the harvest schedule. Characteristically, the yields are maximized when the planting densities are between about 5,000 and 11,000 plants per acre (a cornfield has between 20,000 and 28,000 stalks per acre), and the harvest schedule consists of a first harvest when the stand is a year or two old followed by five to seven additional harvests at two to three-year intervals thereafter.

Using the growth simulation model developed in Appendix C and actual yield data, estimates have been made of the maximum annual yields per acre which can be expected from eight representative deciduous tree species grown under plantation conditions at various widely separated sites (see Appendix C, Section VIII.A.). It is concluded that by properly selecting the species, planting density and harvest schedule, an average annual yield of between eight and nine dry tons of plant matter probably can be harvested almost anywhere in the eastern and central time zones in the United States.

TABLE XI

A REPRESENTATIVE LIST OF DECIDUOUS SPECIES WHICH SHOW PROMISE FOR PLANTATION CULTURE AND LOCALITIES WHERE THEY HAVE GROWN WELL IN MANAGED PLANTINGS

Locality	Hybrid Poplars													
	NE 388, 49 and 252	Others	Aspen & Hybrids	Black Cottonwood	Red Alder	Sycamore	Pin Cherry	Plains Cottonwood	Eastern Cottonwood	Silver Maple	European Black Alder	Green Ash	Sweetgum	Eucalyptus
New Hampshire			X				X							
Wisconsin		X	X											
Minnesota			X											
North Dakota								X						
Washington		X		X	X									
Pennsylvania	X	X												
Ohio											X			
Indiana									X					
Illinois									X		X			
Nebraska									X					
Kansas								X	X	X		X		
Georgia						X						X	X	X
Alabama									X		X		X	
Mississippi						X			X					
Louisiana									X					
Texas									X					
Florida														X

VI.C.4. Perennial Grasses. Certain perennial grasses are also promising sources of raw material for SNG production and for use as solid fuel. There are two broad categories of grasses which grow widely in the United States--the so-called cool-season grasses and the warm-season grasses. The cool-season grasses are frost-resistant, but the warm-season varieties are not.

Perennial grasses can be reproduced vegetatively, and they regrow rapidly after a harvest has been reaped from them. They are similar in these respects to the deciduous tree species previously discussed. More than one harvest can be reaped from them every year, but the actual number depends on the length of the growing season and the regularity and amount of rainfall and ambient temperatures during the growing season.

In those parts of the country where frosts occur for prolonged periods every winter and, hence, where only the cool-season perennial grasses will grow, two or three harvests can usually be taken every year. Annual yields under these circumstances are three to five tons of dry material--a yield too low to be practical for Energy Plantations.

Warm-season grasses, on the other hand, are promising candidates for Energy Plantations in southern locations providing there is sufficient soaking rain (two to three inches per month) during the growing season. In many localities in the deep south, rainfall is adequate to support harvests once every three to four weeks throughout the year from late February into November. Under these circumstances, yields between eight and ten tons per year of oven-dry material are reported for managed grasslands. Moreover, warm -season grasses will probably yield about twenty percent more methane per dry pound of plant material than is produced by plant matter from deciduous tree species. Thus, since the yield of plant matter from warm-season grasses in localities suited to them is comparable with that from deciduous species, warm-season grasses are likely to produce more methane per acre of plantation than can be

TABLE XII

PROMISING WARM-SEASON GRASS SPECIES FOR ENERGY PLANTATIONS

Species	Localities[1]	Annual Yields[2]	Comments
Perennial Sorghums and their hybrids	Plains, South, Southwest	High	Sudangrasses, Johnson Grass and other warm-season hybrids are promising for localities with alkaline soils - they provide several harvests per year
Bermudagrasses Coastal Midland Suwanne	South and South Central States	High	Most promising of all warm-season grasses, especially for localities with acid soils - they can be harvested several times per year
Sugarcane Relatives	Lousiana and Florida	Very High	Limited suitable sites?
Bamboo Relatives	South Central United States	Untested	
Bahiagrass	Florida and southern coastal plains	High	Competes with bermudagrasses when fertilized - effect on overall yield is in dispute

1. Regions in which species grow naturally, or have been sucessfully introduced, or have been extensively tested.

2. High means in the range of 8 to 10 dry tons per acre-year and very high, may be as much as 20 dry tons per acre-year in specially suitable sites.

produced from deciduous tree species. Certain warm-season grasses are, therefore, promising candidates for SNG plantations in those parts of the deep south where the rainfall is regular and two or more inches per month. They are particularly indicated for Florida and near the coast around the Gulf of Mexico. Promising warm-season grasses are briefly described in Table XII.

VI.D. Final-Fuel-Form Considerations. The plant material grown in Energy Plantations might be used as solid fuel after partially drying it. Alternatively, it might be converted into a gaseous or liquid fuel by pyrolytic or biological processes. Consideration has been given to these possibilities. Their practical feasibilities has been assessed for large troop training centers in unurbanized areas. Feasibility has been evaluated on the basis of:

- the ease with which the final fuel can be stored.
- the yield of the final fuel form per unit weight of plant material harvested from the plantation;
- thermal efficiency of the conversion process; and
- ready availability of backup fuels which could be substituted for the fuel produced from the plant material.

The results of these analyses, summarized in Table XIII, lead to the conclusion that using the harvest from plantations either directly as a solid fuel or converting it to synthetic natural gas by anaerobic fermentation are the only two final fuel forms worthy of thorough consideration (see Appendix B, Sections III and IV).

TABLE XIII

SUMMARY OF FINAL-FUEL-FORM CONSIDERATIONS

Final Fuel Form	Conversion Process	Heating Value - Percent of Heating Value of Air-Dry Plant Matter**	Relative Plantation Area Required	Major Disadvantages S=Serious T=Tolerable	Candidate For Troop Training Centers
Solid	None-	100	1.0	Needs partial drying-(T) & airborne particulates control-(T)	Yes
Fuel Gas	Pyrolysis-directly heated	less than 100	more than 1.0	Heating value (150 to 300 Btu per SCF*)-(S), No back-up fuel-(S), Storage problem-(S)	No
Fuel Gas	Pyrolysis-indirectly heated, high temperature (over 1400°F)	less than 100	more than 1.0	Heating value (400 to 600 Btu per SCF*)-(S), No back-up fuel-(S), Storage problem-(S)	No
Fuel Oil	Pyrolysis-indirectly heated, intermediate temperature (∿900° to ∿1000°F)	50 to 60	1.1 to 1.6	Requires heating before firing-(S), Possible poor shelf life-(T)	No
Synthetic Natural Gas	Anaerobic Digestion	65 to 85 (woody raw material) 60 to 70 Grassy raw material)	1.2 to 1.5 (woody raw material) 1.1 to 1.3 (grassy raw material)	Storage problem-(T)	Yes
Synthetic Natural Gas	Spano Technology	less than for direct anaerobic digestion	Larger than for direct anaerobic digestion	Probably lower CH_4 yield and higher costs than for direct anaerobic digestion-(S)	No
Ethyl Alcohol	Spano Technology	40 to 45	2 to 2.7	Low alcohol yield from plant matter-(S)	No

* SCF = Standard Cubic Foot - at 60° Fahrenheit and one atmosphere.

** Entries in this column are heating value of the indicated fuel as a percentage of the heating value of the air-dry plant matter directly used for producing the indicated fuel--*the entries do not take account of the fuel required to provide the mechanical energy and heat required to operate the conversion process.*

VII. PREDICTION OF PLANT-MATTER PRODUCTION RATES FROM DECIDUOUS SPECIES

Previous work[8] has indicated that certain deciduous tree species are preferred for Energy Plantations in most localities where plantations are likely to be practically feasible. Means for predicting the relationships for these species between their harvestable yield on the one hand and local climate, soil quality, the combination of planting density and harvest schedule and other factors on the other,are needed for assessing the feasibility of Energy Plantations. Development of these relationships is the subject of Appendix C. The relationships are briefly described in the following.

Generally speaking, deciduous species produce annual plant-material yields in the range of interest for Energy Plantations when they are grown at densities between about 5,000 and 11,000 plants per acre,and at least five to seven harvests are taken from each stand, the harvests being at two to three-year intervals.

VII.A. Analysis of Available Data. Sets of data useful for devising a system for predicting plant-material production rates are available for about fifteen species and varieties grown in about as many sites in the Midwest and South. In a few instances, data are available for a particular species at more than one site, and in others for several species at a particular site.

It has been found that an effective way to correlate the yield data is to express yields as the product of the number of living plants surviving to harvest time, and the harvestable weight per plant at that time. When this is done, regression analysis shows that the most important factors influencing survival rates, other than the particular species involved, are the age of the stand when it is first harvested and the original planting density expressed as the number of plants per acre. Further analysis allowed development of an approximate generalized means for estimating survival rates when data are not available for specific species-plantation site combinations.

Regression analysis shows that the harvestable yield per plant is strongly dependent on the species, the planting density, whether the harvest is the first from the stand or a subsequent one, and the age of the plant material being harvested. Patterns were noted from the results of the regression analysis and approximate generalized means for estimating yields per plant when actual data are not available have been devised.

The available yield data also indicate that harvestable yields are influenced by cultivating the plantation site, fertilization and climate.

<u>VII.B. Effect of Cultivation on Plant-Matter Production Rates</u>. It is very clear from the data that allowing the species being grown for fuel value unrestricted view of the sun is crucial for achieving high yields. Preventing weeds and tramp vegetation from shading the "Btu Bushes" while still small is therefore necessary, and its cost is included in the plantation capital and operating cost estimations. The data indicate that mowing between the Btu Bushes is a fairly effective way for maintaining weed control, but the most effective way is disking between the bushes. Thorough destruction of the plant matter at the site prior to its use as an Energy Plantation is also an important factor in weed control during the first few years.

<u>VII.C. Effect of Fertilization on Plant-Matter Production Rates</u>. It is important to distinguish between fertilizing a stand when it is first planted and maintaining the productivity of a plantation site. The data indicate

that fertilizer applied at or near the time of planting often leads to low plant survival rates which are only approximately offset by the increase in yield from plants which survive. On the other hand, the survival rates and harvestable yield per plant are each higher in fertile sites than in less fertile sites from species well adapted to the sites. Therefore, to assure continuing high yield at a plantation site, fertilizing factors must be returned to the land to replace those removed with the harvested material, but stands which have not yet established themselves should not be fertilized.

The ash from plant material burned as a solid fuel will be returned to the plantation site for disposition and to recycle its fertilizer values. However, fixed nitrogen will have to be made available also, because it is not recovered in the ash. When the plant material from the plantation is used as raw material for making SNG, the spent sludge from the digestion step will be returned to the plantation for disposition and to recycle its water content and fertilizer values. In this case, the sludge is a total fertilizer for the plantation, and consequently,no supplemental fertilizing will be needed. The cost of ash or spent-sludge return to the plantation land are included in the cost estimates for plantations.

VII.D. Effect of Climate on Plant-Matter Production Rates. It is known that the yield from a particular deciduous species at a given site is influenced by the duration of the frost-free period each year, the profile and absolute levels of ambient temperature during the frost-free period, and the insolation rate at the site. The estimated effects of these three factors have been reduced to equations usable for species selection and yield-estimation purposes. The equations have been approximately validated.

VII.E. Application of the Deciduous-Species Growth-Prediction System. The system includes twelve relationships in addition to specification of species. A program for manipulating it by computer has been written,and the system has been validated by demonstrating its use for predicting yields from several species at a variety of sites. Comparison of predicted yields with actual yields leads to the conclusion that yield predictions are good to probably plus or minus twenty percent for a particular species at a given site, but that for a group of species adapted to a particular site, the yield prediction is probably reliable to within about plus or minus ten percent.

VIII. SYNTHETIC NATURAL GAS PRODUCTION FROM PLANT MATERIAL

Plant material harvested from plantations can be used at troop training centers for making synthetic natural gas. The process involved is an anaerobic digestion of the plant material, which produces a mixture of methane and carbon dioxide and biological cell matter. The only effluents from the digestion step are the mixed-gas stream and a spent-sludge stream containing undigested materials from the plant matter and biological cell material dissolved in and suspended in water. It is expected that about 4.5 standard cubic feet (measured at one atmosphere and 60° Fahrenheit) or a little more of methane can be produced per dry pound of deciduous plant material charged to the system. The yield from plant material produced by warm -season grass species is expected to be about 5.4 standard cubic feet or a little more of methane per dry pound of plant material charged to the anaerobic digester.

The process engineering and costs for the recommended synthetic-natural-gas production process are the subject of Appendix D. The following discussion is a summary of the more detailed coverage in the appendix.

VIII.A. Composition and Structure of Plant Material. Plant material is composed mostly of cellulose and other polysaccharides (sixty to seventy percent by weight of dry material), together with lignin (about twenty--five and nine percent in woody and grassy plant material, respectively), other organic materials and a small quantity of inorganic substances usually described as ash. The lignin and ash are inert under anaerobic digestion conditions. The polysaccharides and other organic materials can be made readily digestible.

The composition of plant mater varies between major species classes. Grasses contain more digestible material than do deciduous tree species, a fact which accounts for the higher yield of methane expected from the former than from the latter.

The physical structure of plant material from grasses is such that their substance is more accessible to biological attack than is material from deciduous species. In the absence of any processing prior to digestion, grass plant material digests more quickly than does woody material.

VIII.B. State-of-the-Art. Only a few experiments apparently have been made to study anaerobic digestion of woody plant material. Experiments to determine whether wood residues of the kind found in solid waste can be consumed by anaerobic digestion have generally shown that woody material of this type does not digest to any significant extent[11,12]. However, it is well known that pure cellulose digests readily under anaerobic conditions, and in particular, relatively pure cellulose prepared from a powdered kraft paper pulp has been found to digest[13]. This material is not exactly like the material produced from Energy Plantations, but of the data available, those compiled for the powdered kraft are the most nearly applicable for the proposed SNG process.

A second category of previous experiments is concerned with rendering wood digestible by ruminant animals. In these experiments, wood was treated in various ways and then exposed to rumen fluid, which is biologically active. While these data on the rate and extent of digestion by rumen may bear little direct relation to the rate of digestion and methane yield in the proposed process for making SNG from plant material, they are useful for indicating the relative digestibilities of various woody species and the effects of various pretreatments on promoting digestibility of woody material. A fact of particular importance is that softwoods are much more difficult to prepare as animal feed and are much less digestible than hardwoods. The data also constitute proof that woody plant material can be made digestible with suitable pretreatment, but it is clear that the rate and the extent of digestion are species dependent.

A third category of previous experiments conducted as part of a waste management study show that in a fifty-fifty mixture with sewage sludge, grass clippings ground to a powder in a hammmermill digested readily[12].

Exploratory experiments aimed at methane production are reported on the anaerobic digestibility of various fresh-water and marine plants[14] and of elephant grass[15]. In each case, physical pretreatment was required to achieve notable digestibility of the plant matter.

It is clear from these experiments that some kind of pretreatment is necessary to make plant material digestible at a reasonable rate under anaerobic conditions.

VIII.C. Ideal Species for SNG Production. Because few appropriate data are available, identification of plant species specially suited for SNG production by anaerobic digestion must be inferred from consideration of the rate and the degree to which various species are susceptible to chemical and biological attack. An additional consideration is the potential yield of methane from a particular species.

On the basis of these consideration, the ideal woody Btu Bush is a hardwood rather than a softwood, and various hardwood species noted for their reactivity and lack of durability are to be preferred. Hardwoods in general have less lignin and more hemicellulose than softwoods, and the type of lignin in hardwoods makes them less decay resistant than softwoods. In addition, the hardwoods in general have a greater potential yield of methane than the softwoods because they contain more digestible material.

By these standards, the deciduous species preferred for SNG raw material fortunately happen to be the same as those preferred for Energy Plantation culture.

Plant material from warm-season grass species is also satisfactory for SNG production.

VIII.D. Pretreatment of Plant Material Prior to Anaerobic Digestion The data available indicate that when plant material from deciduous woody species or warm-season grasses is pretreated in a process involving steeping in steam or hot water and grinding, it becomes digestible at a reasonable rate under anaerobic conditions. Pretreatment processes involving alkalis, acids, and other materials are considered in the literature, but none of these other processes seems to be any more effective than a combination of steeping in hot water or steam and grinding. Moreover, each of these other processes involved materials supply and disposition problems not encountered with the steeping and grinding processes.

Steeping in steam or hot water, or grinding promotes anaerobic digestibility of plant material, but experiments reported in the literature show that a combination of steeping and grinding is more effective than either steeping or grinding alone. There are trade-offs between the extent of grinding and the severity and duration of steeping. These trade-offs have been examined to the extent possible with the data available for three process sequences--extensive steeping in steam followed by grinding, extensive grinding followed by a brief steeping in steam and extensive grinding followed by steeping in hot water for a short time. Material balances, energy requirements and capital costs have been estimated for each of the process sequences. The third possibility--extensive grinding followed by steeping in hot water--appears to be the most attractive in terms of energy required, capital cost and operational convenience. That process sequence, therefore, has been used for estimating the performance and costs of producing SNG for use at Army bases from plant material.

It must be noted, however, that the relationships are not well defined in the literature between grinding energy applied to plant material and the change in its rate of anaerobic digestion, the extent to which components from the plant material are rendered soluble in water, and the highest concentration of the ground material slurried in water which is pumpable. The greater each of these effects is, the less the capital and operating costs of the SNG production process become. These gaps in the data available for process design are a reason for recommendation C.1.

VIII.E. Anaerobic Digestion of Plant Material. Operation and design of the anaerobic digesters are examined from estimated materials balances around them. The published data[13] on methane production from anaerobic digestion of ground kraft paper pulp are the basis for the material-balance estimates. It is assumed, in conformity with the published data, that ninety-three percent of the digestible organics (that is the organics in the plant material except the lignin) is digested in fifteen days, and that the undigested digestible material is cellulose.

For estimating the material balances, each major component of the plant material (cellulose, pentosans, and so forth) is considered separately, because there are differences in the amounts of methane, carbon dioxide and bacterial cell matter produced by unit weights of each of the components. The amount of fixed nitrogen and phosphorus required for good digestion process operation are also estimated, as is the materials requirement for maintaining the pH in the desired range (6.8 to 7.2) in the digester.

Provision is made for filtering the spent sludge from the digester on a rotary vacuum filter. The filtrate is recycled to steeping tanks in the pretreatment process, thereby conserving water and the fixed nitrogen and phosphorus required for steady operation in the digester. The filter cake (estimated to be about twenty-five percent solids and seventy-five percent water) is recycled to the plantation for disposition and for conservation of its water and its fertilizer values.

<u>VIII.F. Methane Purification</u>. The gas evolved from the anaerobic digester is a mixture of methane and carbon dioxide at about atmospheric pressure and 140° Fahrenheit saturated with water vapor. By volume, on a dry basis, the gas is between about fifty and perhaps as much as sixty percent methane. The possibility that it may be much more than fifty percent methane is based on recently received information[10]. The material balances around the anaerobic digester are based on the assumption that it is fifty percent methane. The heating value of the mixed gas is about five hundred Btu per standard cubic foot.

The gas mixture would be satisfactory for use in directly fired equipment built for natural gas, providing the proper gas jets are installed in the equipment and the air-to-gas ratio is appropriately adjusted. But after making these changes, the only backup fuel which could be acceptable is an inventory of the gas mixture itself. But the mixture is difficult to store--one average day's supply for Fort Benning stored at six hundred pounds per square inch would require a spherical pressure vessel about eighty feet in diameter. The capital cost of storage facilities for a thirty-day supply at Fort Benning would be about $30 million, an amount equal to the cost of the rest of the plant. To provide adequate backup storage would clearly be impractical at Fort Benning or any other major troop training center.

The production of SNG cannot be made to fluctuate according to seasonal demand because the microorganisms involved in the anaerobic digestion cannot adjust very well to a varying feed rate. To produce SNG at a constant rate equal to the maximum wintertime demand would involve an enormous waste of fuel during the summertime, and increased expense.

If the carbon dioxide and water vapor are removed from the gas stream, the resulting pipeline-quality SNG is likely to be attractive to troop training centers, and especially to those which rely these days on natural gas. The SNG can be used interchangeably with natural gas; natural gas is a satisfactory backup fuel. Also, in principle at least, existing natural-gas storage facilities of the gas industry can be used to store temporarily the excess SNG produced at Army bases during the summertime. For this purpose, the gas produced will have to be compressed to pipeline transmission pressure (about 1000 pounds per square inch) and then be injected into the natural gas transmission system through appropriate flow meters. The possibility of storing the SNG in this way has not been discussed with the gas industry.

Standard technology has been assumed for the gas purification train. After consideration of the performance and capital and operating costs of the various processes available for removing the carbon dioxide and drying the gas, the Benfield process (an activated solution of potassium carbonate in water) was chosen for the former and glycol dehydration for the latter. The most satisfactory process sequence from operational and capital and operating costs points of view is to cool the gas mixture to 100° Fahrenheit, compress it to 300 psia, remove the carbon dioxide, cool again and compress to 1000 psia, and finally dry the SNG.

VIII.G. Equipment Requirements and Capacities. Analysis of the various major elements of equipment required in the SNG production process indicates that the disc attrition mill (grinder) in the plant material pretreatment stage is the unit which sets the maximum capacity of the pretreatment and digestion train. The capacity of the largest disc attrition mill regularly manufactured these days is two hundred tons of dry plant material per day, or the equivalent of about 1.78 million standard cubic feet of SNG per day when processing plant material from a deciduous species and about 2.16 million when processing plant material from a warm-season grass. There is wide flexibility possible in the capacity of the gas purification train and process steam boiler required for the SNG production facility.

The physical layout of the recommended SNG production plant consists of one or more plant-matter pretreatment and digestion trains, each having a capacity of two hundred dry tons of plant material per day, serviced by one boiler plant and one gas purification train. It is assumed that the anaerobic digesters are 110 feet in diameter with a side water depth of twenty-six feet. Digesters of this size are about the largest built these days. Four are required in a facility having a capacity of two hundred dry tons of plant material per day. The digesters are assumed to be made of reinforced concrete. The remainder of the required equipment for the SNG facility, that is in addition to the attrition mill and digesters, is selected from standard industrial equipment and materials generally available in the trade.

VIII.H. Energy Balance. There are three energy inputs to the SNG process. They are fuel for process steam, electricity for shaft horsepower and the fuel value represented by the plant material from which the SNG is produced. At least part of the electricity and all the process steam could be provided by a back-pressure turbine driven with high-pressure steam. This possibility has been examined in the course of approximately optimizing the energy balance for the SNG production process, and has been found to be worthwhile. Its effect is, therefore, included in the estimated energy balance for the proposed SNG process. The energy balance assumes that fossil fuel will be used in the boiler plant. Purchased electricity is reflected in the energy balance in terms of the fossil fuel required to generate it, assuming that 9,300 Btu in fuel are consumed at the utility station for every kilowatt-hour of electricity used at the SNG production facility.

The energy balances indicate that the fuel value of the SNG produced is at least between one-third and two-thirds larger than the fuel value in the fuels used to provide the steam and shaft horsepower needed for the process.

VIII.I. Capital and Operating Costs. Capital and operating costs have been estimated for a plantmaterial pretreatment and digestion train having a daily capacity of two hundred tons of dry plant material. Capital and operating costs have also been estimated for the boiler plant and its turbo-generator, and for the gas purification train as functions of the capacity demanded of these units by the appropriate number of pretreatment and digestion trains needed for the SNG production facility at a particular Army base. These cost estimates are used for estimating the cost of SNG produced at Forts Benning and Leonard Wood,and can be used for making similar estimates at other Army bases.

IX. SOLID-FUELED CENTRAL HEATING SYSTEMS

If plant material from the plantation is used as solid fuel, it will be necessary to replace the many small-capacity heaters in use at Army bases with central heating systems. Such is so because solid fuel cannot be burned very effectively in small- capacity unattended heating equipment,which at many bases is the major consumer of fuels.

The capital and operating costs for a central heating system at a particular base not only depends on the scale of operations at the base, but also on the extent of any existing central heating system and the compactness of the building arrangement at the base. Moreover, since it is not practical to store either large quantities of steam or hot water (where "large quantities" means amounts commensurate with the difference in heat demand between seasons), the capacity of the boilers in the central heating plant is a function of the peak heating demand, which in turn is a function of the coldness of winter and scale of operations at the base.

The facilities required in central heating systems (and hence also their costs) are influenced, therefore, by a wider variety of factors peculiar to a particular base than is the case for SNG production systems for Army bases. It is not as practical, therefore, to define unit elements of capacity for central heating systems as it is for SNG production facilities (a pretreatment and digestion train having a capacity of two hundred tons per day of plant material, for instance). Consequently, generalized estimates of the design and costs of central heating systems for Army bases have not been made. Only specific approximate estimates for Forts Benning and Leonard Wood have been made.

In making these specific estimates, it is assumed that saturated steam at 165 psia will be generated in central heating plants equipped with a number of boilers, the capacity of each one being adequate to meet the heat demand in summer. Distribution systems with and without condensate return are considered. The differences in capital and operating costs with and without condensate return are within the range of accuracy of the overall system estimates.

No detailed estimates have been made for the costs of alter ations within buildings which might be necessary to accommodate them to a central heating system. However, such alterations would cost at least $5,000 per building, and this rough estimate has been included in the overall capital cost estimate for a central heating system.

It can be shown that it would be better to harvest plant material at an approximately constant rate throughout the year, than to vary the harvest rate to make it conform to the seasonal need for fuel. It will, therefore, be necessary to accumulate and store harvested fuel during the summer for use in the following winter. Storage costs will be incurred, but because their total will not exceed five percent of the estimated annual cost of operating the central heating system, these costs have not been estimated in detail.

The estimated design and costs for central heating systems at Forts Benning and Leonard Wood are the subject of Appendix E.

X. AN ENERGY PLANTATION SYSTEM FOR FORT LEONARD WOOD

X.A. Design Considerations. In fiscal year 1973, 2.08 x 10^{12} Btu of fuel were used in fixed installations at Fort Leonard Wood. The fuel types used and seasonality in total fuels consumption are shown in Tables VIII and IX. The 1973 fuels consumption will be used as the design basis for Energy Plantation systems for Fort Leonard Wood.

At a production rate of about 4.5 standard cubic feet of SNG per pound of oven-dry plant matter, a plantation supplying the raw material to produce enough SNG to meet the entire fuels requirement in stationary facilities at Fort Leonard Wood will have to grow about 240,000 oven-dry tons of harvestable plant material from deciduous species per year. If the fuel needs are to be met with solid fuel, the capacity of the plantation will have to be about 180,000 oven-dry tons of plant material from deciduous species per year.

Fort Leonard Wood is located in south-central Missouri at an elevation of about 1,200 feet. Its climate is typically continental--cold winters and hot summers with temperatures exceeding 90° Fahrenheit on occasion. The growing season for deciduous species is about five months--May to September. Yearly normal precipitation is about forty inches. Although total rainfall during the summer is adequate to sustain high-yield plant growth, the rainfall distribution is unfavorable because it consists of large downpours at irregular intervals often lasting as long as one to two weeks. As a result, droughty conditions--typical of continental climates--generally occur from the end of July to the end of August.

The soil types of the largest land areas probably available for plantations are generally cherty and retain little of the rainfall available during the growing season. Thus, the combination of poor rainfall distribution and poor moisture retention in the soil is probably the limiting factor as far as plant-matter yields are concerned. A detailed discussion of these problems is given in Appendix F.

Excluding the areas used for troop training and other purposes, the land area probably available for plantations on the base itself is about 17,000 acres (see Appendix H).

A summary of the main estimates for plantation systems at Fort Leonard Wood is compiled in Table XIV.

X.B. Selection of Plant Species. Because of the relatively short growing season and cold winters, grasses would not be satisfactory species for plantations at Fort Leonard Wood.

For the largest areas suitable for plantation purposes--the sloping hillsides--certain hybrid poplars and varieties of plains cottonwood are the most desirable species. For the limited bottomlands available, eastern cottonwood, sycamore, silver maple and certain hybrid poplars are recommended. This selection of species is established on the basis of data collected during site visits in Pennsylvania, Iowa, Kansas and Georgia, and from a number of experts including several with intimate familiarity with the Fort Leonard Wood area.

X.C. Estimated Plant-Material Production Rates and Plantation Area Requirements. Expected annual sustained yields have been determined for the species of interest using the tree-growth simulation model and optimization procedure described in detail in Appendix C.

It is estimated that the average annual sustained yield from deciduous species preferred for the Fort Leonard Wood area is about 8.3 oven-dry tons per acre-year. The expected range of values for the sustained yields extends from slightly over 7 oven-dry tons to about 9.2 oven-dry tons per acre-year. This range in yield can probably be achieved with any of the species identified in section X.B., providing the planting stock chosen is well adapted to the particular growing conditions in the Fort Leonard Wood area. The planting density-harvest schedule combination for achieving the estimated yields is four square feet per plant at planting (about 11,000 plants per acre), first harvest one year after planting, subsequent harvests at two-year intervals and a total of six harvests before replanting the stand. Thus, it is expected that a given planting will supply plant material for a period of eleven years, after which the stumps will be removed and a new planting established. To avoid periodic interruption of plant-material production, an eleventh of the plantation area will be replanted every year. A small fraction of the plant material grown every year will be used for replanting stock. The estimates of plantation area required take these replanting requirements into account.

At the estimated average sustained yield of 8.3 oven-dry tons per acre-year and taking into account the partial yearly renewal of the planting, an area of about 29,000 acres is estimated as necessary for supplying the raw material for SNG production, while an area of about 22,000 acres will be necessary if solid fuel is to be produced. However, as discussed in Appendix H, only about 15,000 acres is estimated to be available so that only part of the fuel requirements for Fort Leonard Wood could be satisfied by using land on the base itself for an Energy Plantation.

TABLE XIV

SUMMARY OF PLANTATION SYSTEM ESTIMATES FOR FORT LEONARD WOOD

Estimated Factor	Units	For Solid Fuel			For SNG		
		Low	Probable	High	Low	Probable	High
Average Annual Sustained Plant Material Yield	dry tons per acre-year	7.4	8.3	9.2	7.4	8.3	9.2
Plant Material Required	dry tons per year	180,000	180,000	180,000	240,000	240,000	240,000
Required Plantation Area	acres	24,300	21,700	19,600	32,600	29,000	26,100
Plantation:							
-Planting density	sq. feet per plant	4	4	4	4	4	4
-Age at first harvest	years	1	1	1	1	1	1
-Interval between harvests	years	2	2	2	2	2	2
-Harvests per planting		6	6	6	6	6	6
-Establishment Cost	$	$5.7x10^6$	$5.4x10^6$	$5.1x10^6$	$7.9x10^6$	$7.5x10^6$	$7.2x10^6$
-Annual operating cost	$/year	$2.3x10^6$	$2.3x10^6$	$2.2x10^6$	$2.8x10^6$	$2.8x10^6$	$2.7x10^6$
-Cost of plant material	$ per dry ton	12.80	12.70	12.40	11.80	11.70	11.40
-Cost of plant material	$ per 10^6 Btu	1.10	1.09	1.07	1.02	1.01	0.98
-Work force:							
full-time	people		79			127	
part-time	man-months per year		167			222	
Central Heating or SNG Systems:							
-Boilers or pretreatment-digestion trains			3			4	
-Steam generating capacity	lb per hour		600,000			-	
-SNG production capacity	SCF per day		-			$7.1x10^6$	
-Plantation Establishment Cost	$		$5.4x10^6$			$7.5x10^6$	
-Cap. Cost of heating plant and distribution	$		$34.9x10^6$			-	

TABLE XIV (continued)

SUMMARY OF PLANTATION SYSTEM ESTIMATES FOR FORT LEONARD WOOD

Estimated Factor	Units	For Solid Fuel			For SNG		
		Low	Probable	High	Low	Probable	High
-Capital cost of SNG facility	\$		-			$25.3x10^6$	
-Total capital cost	\$		$40.3 x10^6$			$32.8x10^6$	
-Cost per 10^6 Btu per year at present fuel use rate	\$/10^6 Btu/year		19.40			15.80	
-Annual operating cost	\$/year		$6.3 x10^6$			$8.0x10^6$	
-Annual cost per 10^6 Btu at present fuel use rate	\$/year		3.04			-	
-SNG cost per 10^6 Btu	\$/10^6 Btu		-			3.74	
-Work force							
Plantation-full-time	people		79			127	
Central Heating or SNG - full-time	people		88			93	
Total full-time	people		167			220	
Part-time	man months/year		167			222	

A sensitivity analysis shows that if land availability permits and, more specifically, if about fifteen percent more land than the areas first mentioned can be made available, a planting density of eight square feet per plant (about 5,500 plants per acre) with a first harvest at one year and subsequent harvests at three-year intervals produce yields about ten percent lower than those estimated for a four-square-foot planting density but at a production cost per ton lower by about ten percent also.

X.D. Plantation Operation. Operations under plantation management include planting, harvesting and weed control (by disking) in the plantation, maintenance of the productivity of the land, maintenance of field and transport equipment, delivery of harvested plant material to its point of use at the army base and return of residues (ash or spent anaerobic digester slurry) to the plantation and spreading them on the land, and production of replanting stock. The daily harvesting rate is assumed to be constant throughout the year. As it is harvested, the plant material is chipped--the chips being about like those produced by chippers used in municipalities for small wood collected during maintenance, for instance, of rights of way and parks. Five miles is assumed to be the average distance harvested plant material is hauled from the plantation to the point of use. After allowance for inclement weather, it is assumed there are 230 working days per annum in the plantation, work being on a schedule of one shift per working day.

The only seasonal operations at the plantation are collection and cool storage of replanting stock and replanting. The former takes about three months per year starting after the plants in the plantation have gone dormant for the winter. The latter also takes about three months after the growing season starts in the spring. Most of the work involved in these operations is handled by part-time, relatively unskilled labor.

The only difference in operations between plantations producing plant material for solid fuel and those producing raw material for SNG production is in the work required for maintaining the productivity of the land. Where solid fuel is being grown, about twenty pounds of ash per dry ton of plant material harvested are available for return to the land as fertilizer. However, because the ash is devoid of fixed nitrogen (it is a complete fertilizer with respect to potassium, phosphorus and trace elements), about six pounds of fixed nitrogen must also be applied to the land per dry ton of plant material harvested. The equipment and manpower required for these productivity maintenance operations, and their capital and operating costs, are included in the plantation operation and cost estimates.

When raw material for SNG production is being grown, about 1.5 tons of spent sludge per dry ton of plant material harvested are available from the anaerobic digesters for return to the land as fertilizer. The sludge is a complete fertilizer for the plantation,and no supplemental fixed nitrogen is required. Provision is made for the equipment and manpower required, and consequent costs, for sludge handling and distribution on the land in the plantation operation and cost estimates.

X.E. Plantation Establishment. It will take about three years to establish a plantation when the harvest schedule calls for first harvests from one-year-old plants and subsequent harvests from stump regrowth at two-year intervals. The major operations during the establishment period will be land preparation, planting-stock production, and initial planting. Except for the second of these operations, the work will be done progressively throughout the three-year period. The first harvest for solid fuel or SNG raw material will be in the fourth year and then regularly thereafter.

Land preparation will involve cutting down the vegetation on the site to within an inch or two of the ground, possibly root-raking, followed by intensive disking several times prior to the first planting in the following spring. Access roadways and bridges over ditches and the like will also be built during the land preparation period.

For initial production of planting stock which is at least partially acclimated to the plantation site, a nursery plantation will be established in the first year on land which requires the least preparation and is reasonably fertile. The area required will be about a tenth of the ultimate area planned for the plantation. Planting stock--clones--will be first harvested from the nursery for use in the plantings scheduled for the second year in the plantation establishment schedule. Clones for planting in the third year of the schedule will be cut from the nursery and from the stands planted in the second year. A nursery as such will no longer be needed after the end of the second year because in later years clones will be collected in the course of the regular harvests from the plantation.

The initial planting operations will be similar to those to be undertaken regularly in the plantation operation, except that more intensive weed control (disking between plants) may be necessary in the period following the first planting than is expected to be required after the plantation is well established.

X.F. Plantation Organization. The analysis in Appendix F, section V.B.1, indicates that for effective use of field machinery, transport equipment and manpower, the plantation should be divided into compact land units having a production capacity of about 40,000 dry tons of plant material per year. Each of these production units makes essentially full-time use of the major equipment assigned to it, and hence also of the crew required to operate the equipment.

Estimates of the manpower and equipment required per production unit having a production of 8.3 dry tons of plant material per acre-year at Fort Leonard Wood are shown in Table XV. Comparable estimates for the lower and higher plant-material production rates shown in Table XIV are very similar to those shown in Table XV. Such is the case, because the plant-material handling rate, on a weight basis, of the major equipment is essentially unaffected by the differences in distance travelled per unit weight of plant material handled in the range of yields per acre-year shown in Table XIV. However, two of the seasonal operations, clone production and planting, are sensitive to the yield per acre-year. For them, therefore, the equipment-hours and man-hours required vary with the growth rate per acre-year. But since the equipment is used only briefly during the year for these operations, the effect reflects itself primarily in hours required to do the work, and hence in the cost of the work, and not in the units of equipment required. This point is illustrated in Appendix F, section V.B.3.

For plant material grown for SNG production, six plantation production units will be required for Fort Leonard Wood. If the plant material is to be used as solid fuel, 4.5 production units will be required. Because of the half unit required for solid fuel, major machinery and full-time manpower will not be used quite as effectively if solid fuel is grown than it would be if material for SNG is grown.

The supervisory group will consist of five persons irrespective of whether solid fuel or SNG raw material is being produced. The motor pool, which will also be responsible for maintenance of field and transport equipment, will require more people and a larger equipment reserve at an SNG plantation than at a solid-fuel plantation. Supervision and maintenance will be housed in the same building. The estimated staffing and reserve equipment requirements for these two functions are summarized in Table XVI. The requirements are not affected by the yield per acre-year in the plantation.

The total work force, by skill, estimated to be required for plantations growing solid fuel and raw material for SNG at Fort Leonard Wood are shown in Table XVII. Also shown are the estimated pay rates by skill level.

X.G. Cost of Plantation Establishment. The cost of establishing a plantation will depend on its area, the number of plants to be planted per acre and the condition of the land to be used. Grassland, for instance, will usually cost less to make ready for initial planting than will land on which scrub trees are growing.

The estimated land clearing and preparation costs used for plantation establishment at Fort Leonard Wood are based on representative field equipment hours required per acre used by InterTechnology's agricultural engineering consultants[9] in their work. The lime and fertilizer required for soil conditioning are also based on representative estimates provided by the same consultants. The costs of clone production and planting, lime and fertilizer application, cultivation after planting, supervision and equipment maintenance are based on the estimates of these costs for these operations after the plantation is established (see section X.H.).

TABLE XV

ESTIMATED MANPOWER AND EQUIPMENT REQUIREMENTS FOR PLANTATION PRODUCTION UNITS YIELDING 40,000 DRY TONS OF PLANT MATERIAL PER YEAR AT FORT LEONARD WOOD

Equipment				
Type	Estimated Purchase Cost[4]	Estimated Service Life Years	Equipment Units	Personnel F - Full-time P - Part-time
Year-long Operations:				
Harvesters	$50,000 ea.	5	5	5-F
Chip hauling:				
-Trucks	16,700 ea.	5-10	5	5-F
-Tractors	12,000 ea.	6	2	2-F
-Dump Wagons	5,000 ea.	8	7	-
Sludge trucks[2]	17,500 ea.	5-10	4	4-F
Seasonal Operations:				
Tractors	12,000 ea.	5	3	3-F
Crawler Tractor	33,000 ea.	6	0.3	0.3-F
2-Row planters	1,100 ea.	15	3	14 mm-P[1]
4-Row cultivators	2,000 ea.	5	2	-
Sidedressers[3]	500 ea.	1	1	-
Pesticide sprayer	2,600 ea.	5	1	-
Clone collection:				
-Pickup truck	5,600	5	1	23 mm-P[1]
-Trailer	2,300	15	1	-

Note 1: mm = man-months - total part-time work (37 man-months per year) could be done by seven people, each working about 5.5 months a year.

Note 2: Required only when plant material is grown for SNG production.

Note 3: Required only when plant material is grown for solid fuel.

Note 4: Prices in effect in December, 1974.

The estimated costs of plantation establishment include all the costs expected to be incurred in the three years following the time when work at the plantation site is started. The costs do not include any cost for the land used because it is assumed that the land to be devoted to the plantation is already held by the Department of Defense.

The cost of plantation establishment is more fully discussed in Appendix F, section V.C.3.

The major sources of estimated cost for plantation establishment at Fort Leonard Wood are summarized in Table XVIII. The cost estimates are based on prices in effect in December 1974 and the personnel pay rates shown in Table XVII. It will be seen that next to the estimated cost of equipment and facilities, the costs of clones and their planting are, as a group, the second largest source of estimated cost--about a third of the total estimated. As is to have been anticipated, the estimated plantation establishment costs are notably lower for plantations producing plant matter for solid fuel than those for plantations producing raw material for SNG production. The effect of variations in the average annual plant-material growth rate on the estimated cost is small, and the differences in the cost estimates attributable to this factor are probably within the range of the accuracy of the estimates themselves.

X.H. Plantation Operating Cost. The cost of plantation operation has been estimated on the basis of equipment production rates and capacities and equipment and facility requirements for maintenance, fuels, supplies and manpower estimated by InterTechnology's agricultural engineering consultants[9]. In making their estimates, the consultants reviewed the anticipated operating conditions in Energy Plantations with manufacturers of farm and forestry equipment for additional opinions on the factors which will have a bearing on plantation operating cost.

TABLE XVI

ESTIMATED MANPOWER AND EQUIPMENT REQUIREMENTS FOR SUPERVISION AND MOTOR POOL FOR PLANTATIONS AT FORT LEONARD WOOD

Personnel	Equipment	Personnel For Solid Fuel	Personnel For SNG Raw Material
Supervision:			
General foreman	1 pickup truck	1	1
Horticulturist	1 pickup truck	1	1
Motor pool foreman	1 pickup truck	1	1
Field foreman	1 pickup truck	1	1
Secretary-dispatcher		1	1
Motor Pool:			
Mechanics	2 pickup trucks	5	
Mechanics	3 pickup trucks		6

Reserve Equipment Assigned to the Motor Pool

	For Solid Fuel	For SNG Raw Material
Harvesters	2	3
Chip trucks	2	3
Chip dump wagons	4	4
Sludge trucks	-	2
Tractors	2	3

The estimated operating cost also includes allowance for the cost of replacing worn-out equipment. This cost is a substantial part (about twenty percent) of the estimated total operating cost, because the useful lives of most of the equipment in plantation service will be less than ten years (see Table XV). The estimated operating cost also includes provision for maintenance of roads, bridges and the like on the plantation, but does not include any provision for the cost of land used for the plantation.

The estimated costs of the plantation operation have been examined from two points of view. The first of these, which is summarized in Table XIX, is an estimate of the costs of manpower (based on the pay rates shown in Table XVII), fuels, spare parts,supplies and so forth expected to be needed for plantation operation at Fort Leonard Wood. The most striking conclusion to be drawn from the estimates shown in the table is that the cost of plant material harvested is relatively insensitive to the average annual yield per acre-year. Since the variations in estimated cost with annual yield for solid fuel and for SNG raw material are undoubtedly within the ranges of uncertainty in the estimates, it is concluded that the probable costs of plant material grown for solid fuel and for SNG raw material at Fort Leonard Wood are about $12.65 and $11.65 per dry ton, respectively. These costs are the equivalent of about $1.09 and $1.00 per million Btu of useful fuel value (the lower heating value) of material which is approximately air-dry. They are, therefore, considerably less than the cost of fuel oils anywhere these days and less than the cost of coal in many parts of the country.

It should be noted that the costs shown in Table XIX and the resultant cost of the plant material harvested do not include various capital charges (e.g., return) which would have to be included in the total cost if the plantation were operated by a contractor for the Army. Overhead costs would undoubtedly be different, also. If the plantation were operated by contract, overall costs would increase by perhaps 30 to 50 percent.

TABLE XVII

ESTIMATED PERSONNEL REQUIREMENTS AND PAY RATES FOR PLANTATIONS AT FORT LEONARD WOOD

Skill Level	Pay Rates $ Per Year	Personnel Requirements: For Solid Fuel	Personnel Requirements: For SNG Raw Material
General foreman	$22,000	1	1
Horticulturist	18,000	1	1
Motor Pool foreman	15,000	1	1
Field foreman	11,000	1	1
Secretary-dispatcher	6,500	1	1
Mechanics	10,000	5	6
Harvester operators	9,100	23	30
Tractor operators	6,500	22	30
Crawler operators	6,900	1	2
Truck drivers	7,500	23	54
Totals		79	127
Unskilled personnel part-time	$ 450/month	167 man-mos.	222 man-mos.

Another point rather clearly brought out by the estimates in Table XIX is that despite the fact that the proposed plantation operations are highly mechanized (all the full-time field personnel are equipment operators), the payroll cost for field personnel is the largest single source of cost for producing plant material. This finding suggests that selecting a relatively smooth, but not necessary flat, plantation site would be beneficial because it would permit use of wider field equipment. For instance, in the estimates it is assumed that two-row harvesters are used, but if the site is relatively smooth, it is conceivable that three or four-row harvesters could be used successfully. Such larger-capacity equipment would reduce manpower requirements, but its overall effect on operating costs has not been investigated.

The second point of view from which estimated plantation operating costs have been examined is shown in Table XX. In this case, the estimated costs of major unit operations are expressed as percentages of the total cost of plantation operation. It is seen that the relatively most costly operation is harvesting, but delivering the material to its point of use is also a major source of cost--about eighteen percent and twenty-three percent for plant material produced for solid fuel and raw material for SNG, respectively. However, in the case of raw material for SNG, it is more realistic to look at the total of the costs of moving the plant material to its point of use and returning the spent sludge to the plantation land, namely thirty-six percent of the total cost of operating the plantation. The cost benefit of establishing the plantation close to the SNG production facility is clearly evident.

X.I. Energy Balance for Energy Plantations. The estimated fuel requirements for plantation operation per ton of plant material delivered five miles off the plantation site are about 210,000 and 260,000 Btu for solid fuel and SNG raw material, respectively (see Appendix F, section V.C.). These requirements are about two percent of the useful fuel value (lower

TABLE XVIII

MAJOR ELEMENTS IN THE ESTIMATED COST OF PLANTATION ESTABLISHMENT AT FORT LEONARD WOOD

(in thousands of dollars, except as noted)

Average Annual Plant-Material Growth Rate-	Plant-Material Production For:					
	Solid Fuel			SNG Raw Material		
Dry Tons Per Acre	7.4	8.3	9.2	7.4	8.3	9.2
Land Clearing and Preparation	290	260	230	400	350	310
Lime and Fertilizer	180	170	160	250	230	210
Lime and Fertilizer Application	140	120	110	180	160	150
Clones Purchased	240	220	190	320	300	260
Clones Production	980	870	790	1,310	1,170	1,050
Planting	800	710	640	1,070	950	860
Cultivation	120	110	100	160	140	130
Harvesting	160	160	150	210	210	210
Motor Pool	70	70	70	100	100	100
Supervision	280	280	280	280	280	280
Totals	3,260	2,970	2,720	4,280	3,890	3,560
Equipment and Facilities	2,400	2,400	2,370	3,640	3,630	3,590
Establishment Cost	$\$5.7\times10^6$	5.4×10^6	5.1×10^6	7.9×10^6	7.5×10^6	7.2×10^6

heating value) of the plant material when it is approximately air-dry. These requirements suggest, even after making liberal allowance for any errors in the estimated fuel requirements, that an Energy Plantation will deliver twenty-five or more times as much fuel value as is consumed in the plantation as gasoline and diesel fuel.

X.J. Sensitivity Analysis of Energy Plantation Operation. The analysis in Appendix C of growth data from deciduous species indicates that the average annual sustained yield from a stand at a particular site is considerably influenced by the species, planting density and harvest schedule selected for the plantation. For Fort Leonard Wood, maximizing the average annual yield of plant material per acre has been the guiding criterion in selecting the species, the density of four square feet per plant and the schedule calling for the first harvest when the stand is a year old, followed by five additional harvests, with two years between harvests. A sensitivity analysis using these selected values as the base point has been made to determine the effect of variations in species, planting density and harvest schedule on the estimated cost of the plant material produced, the plantation area needed to meet the requirements of Fort Leonard Wood and the cost of establishing the plantation. This analysis is summarized in Table XXI and shown graphically in Figure II.

The top row in the table shows the base case; that is, the data for the most probable yield (8.3 dry tons per acre-year) from a plantation producing raw material for SNG at Fort Leonard Wood. The data in lines two and three (dots in Figure II) are the upper and lower limits of the yield per acre-year expected at the fort. For sensitivity analysis purposes, they can be considered as showing the effect of yield variation from causes other than conscious adjustment of planting density or harvest schedule, or they could be the effect of a species change. In any event, as noted in sections X.G. and X.H., plus or minus changes in yield of about eleven percent have only a very small effect on the costs of establishing a plantation or of the plant material produced, at Fort Leonard Wood.

TABLE XIX

ESTIMATED COSTS OF PLANTATION OPERATION AT FORT LEONARD WOOD BY MAJOR SOURCES OF COST

(in thousands of dollars, except as noted)

Average Annual Plant-Material Growth Rate -	Plant-Material Production for: Solid Fuel			SNG Raw Material		
Dry Tons Per Year	7.4	8.3	9.2	7.4	8.3	9.2
Payroll:						
Field personnel	593	583	569	958	944	926
Mechanics	50	50	50	60	60	60
Supervision and Clerical	73	73	73	73	73	73
Admin. and gen. overhead	167	165	162	242	239	236
Equipment replacement	430	430	425	654	654	648
Equipment spare parts	255	255	253	357	357	353
Fuel	108	107	106	190	189	189
Plantation maintenance	96	87	80	128	116	106
Fertilizer	402	402	402	-	-	-
Lime	67	59	53	89	79	71
Pesticides	33	30	27	44	40	36
Misc. supplies	36	36	36	48	48	48
Total Cost	$\$2.3 \times 10^6$	$\$2.3 \times 10^6$	$\$2.2 \times 10^6$	$\$2.8 \times 10^6$	$\$2.8 \times 10^6$	$\$2.7 \times 10^6$
Cost per dry ton of plant material harvested	$12.80	$12.70	$12.40	$11.80	$11.70	$11.40

Data in lines four and five (open triangles in Figure II) show that waiting longer after planting has little effect on the cost of plant material produced, but rather severe adverse effects on the plantation area required and its plantation establishment cost.

The data in lines six through eleven reflect the effects of changing the interval between harvests (solid triangles in Figure II), the planting density (open squares in the figure) and the total harvests taken per planting (open circles). Changes in these factors have similar effects on the cost of plant material produced--that is,the cost declines to a minimum at about seven percent below the base case at about twice the value for each parameter used in the base case. Beyond two times base-parameter variation, further increase in the interval between harvests or decrease in planting density will cause the cost of plant material to increase. Extending the number of harvests from a stand beyond eleven would theoretically cause a further decline in plant material cost, but the rate of decline would decrease as the total number of harvests increases. It must be noted, however, that there are no data on whether deciduous species maintain their regrowth vigor beyond six harvests (see Appendix C, sections IV.A.8. and V.B.5.).

Reference to Table XXI shows, however, that increasing the interval between harvests to three or four years leads to a substantial increase in plantation area (twelve and twenty-five percent at three and four-year intervals, respectively),and first to a decline (at three years) and then a ten percent increase in the plantation establishment cost.

TABLE XX

ESTIMATED COSTS OF MAJOR PLANTATION OPERATIONS AS PERCENTAGES OF TOTAL PLANTATION OPERATING COST

	Plant-Material Production for:	
	Solid Fuel	SNG Raw Material
Harvesting	30%	33%
Plant-material delivery to point of use	21	23
Fertilizer	18	-
Sludge return to the land	-	13
All other field operations	14	14
Supervision	5	4
Clone production	4	4
Motor pool	4	5
Plantation maintenance	4	4
	100%	100%

Increasing the planting area per plant (decreasing the planting density) causes a moderate increase in the plantation area required (seven or eight percent) and a substantial decrease (about fifteen percent) in the cost of establishing the plantation. Serious consideration should, therefore, be given to possibly increasing the planting area per plant, if seven or eight percent more land can be made available than is required for planting at four square feet per plant (the base case).

The only way to find out whether increasing the total harvests beyond about six is possible without loss of regrowth vigor is to watch the yields from a regularly harvested stand over a period of ten to twenty years. The effect, however, of additional harvests beyond the fifth or sixth on plantation area required and the cost of establishing the plantation is small--about a five percent reduction in each case.

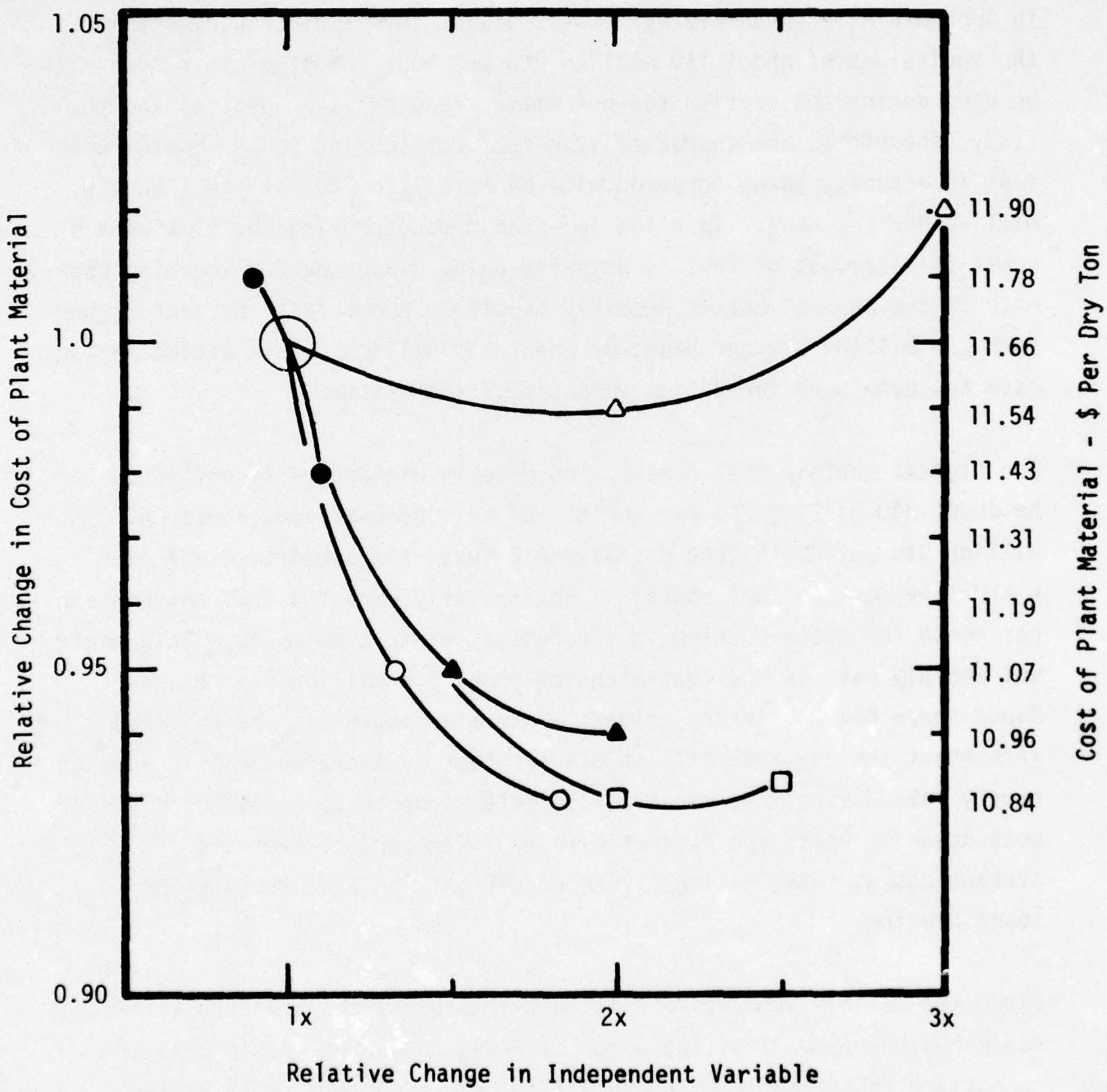
Similar sensitivity analyses of estimates made for plant material grown for solid fuel, and for the plant material grown at other Army bases lead to results comparable with those shown in Figure II. It is concluded, therefore, that in any program of experimental plantings, two or three planting densities should be included. It is further concluded, in view of the estimates in lines 8 and 9 compared with that in line 1 of Table XXI, it would be worthwhile to start such a program promptly at one Army base, or more than one, to confirm the yield trends and levels shown in the table. These conclusions are part of the reason for recommendation C.2.a.

X.K. Solid-Fueled Central Heating System

X.K.1. Boiler Capacity and Cost. It is estimated that the normally expected heat load (as measured by the fuel consumption rate) at Fort Leonard

FIGURE II

INFLUENCE OF PLANTING DENSITY AND HARVEST SCHEDULE ON COST OF PLANT MATERIAL FOR SNG PRODUCTION



LEGEND:

- ● Yield
- △ Age at first harvest
- ▲ Interval between harvests
- □ Planting density
- ○ Total harvests per planting

Wood in the summertime is about 80 billion Btu per month (see Table A-XIV in Appendix A). On an average hourly basis, this fuel requirement is the equivalent of about 110 million Btu per hour. Most of this heat will be used during the daytime for hot water, mess halls, laundries and the like. Therefore, the characteristic fuel rate during summer months when fuel is actually being consumed will be more like 220 million than 110 million Btu per hour. To allow for peak demands during the time when a substantial amount of fuel is actually being used, the fuel-burning capacity of the central heater probably should be about fifty percent higher than 220 million Btu per hour, or about 330 million. This estimated fuel rate has been used for design purposes in summertime.

The highest monthly fuel consumption rate in wintertime is estimated to be about 340 billion Btu per month. Of this consumption, about 260 billion Btu per month (the difference between the summertime and peak wintertime monthly fuel rates) is the normally expected fuel consumption per month for space heating in the coldest wintertime month. This maximum monthly rate is the equivalent of about 360 million Btu per hour. Since space heating in the coldest wintertime month will be required throughout the day, 360 million Btu per hour is a characteristic average hourly rate during that month. This rate needs to be adjusted only for peak demands, which are estimated to be fifty percent over the average hourly rate, giving a rate of 540 million Btu per hour for space heating.

Since the maximum summertime fuel rate is about a third of the estimated maximum wintertime rate, and since it would be convenient to meet the summertime requirements with one boiler, three boilers, each having a firing rate of 300 million Btu per hour, are indicated for Fort Leonard Wood.

TABLE XXI

INFLUENCE OF PLANTING DENSITY, HARVEST SCHEDULE AND TOTAL HARVESTS PER PLANTING ON COST OF PLANT MATERIAL FOR SNG PRODUCTION, REQUIRED PLANTATION AREA AND PLANTATION ESTABLISHMENT COST

Bases: 240,000 dry tons of plant material per year at Fort Leonard Wood

Variation Number	Planting Density, Harvest Schedule & Total Harvests[1]				Yield per Acre-Year		Cost of Plant Material Per Dry Ton		Plantation Area Required		Plantation Establishment Cost	
	Ft^2	Yr.	Yrs.	T.H.	Dry tons	Index[2]	$	Index[2]	Acres	Index[2]	$	Index[2]
1	4	1	2	6	8.28	1.00	11.66	1.00	29,000	1.00	$7.50x10^6$	1.00
2	4	1	2	6	7.36	0.89	11.85	1.02	32,600	1.12	$7.92x10^6$	1.06
3	4	1	2	6	9.20	1.11	11.44	0.98	26,100	0.90	$7.15x10^6$	0.95
4	4	2*	2	6	7.62	0.92	11.50	0.97	31,600	1.09	$8.38x10^6$	1.12
5	4	3*	2	6	7.04	0.85	11.87	1.02	34,300	1.18	$9.86x10^6$	1.31
6	4	1	3*	6	7.45	0.90	11.04	0.95	32,400	1.12	$7.02x10^6$	0.94
7	4	1	4*	6	6.62	0.80	10.98	0.94	36,300	1.25	$8.28x10^6$	1.10
8	8*	1	2	6	7.70	0.93	10.86	0.93	31,200	1.08	$6.59x10^6$	0.88
9	10*	1	2	6	7.45	0.90	10.87	0.93	32,200	1.07	$6.26x10^6$	0.83
10	4	1	2	8*	8.47	1.02	11.14	0.96	28,400	0.98	$7.29x10^6$	0.97
11	4	1	2	11*	8.62	1.04	10.83	0.93	27,800	0.96	$2.12x10^6$	0.95

Footnote 1: The entries should be read: planting density 4 ft^2 per plant, stand 1 year old at first harvest, 2 years between harvests, and a total of 6 harvests from a stand before replanting it. The asterisk indicates the factor varied from the base case (top row).

Footnote 2: The value shown in the column to the left divided by the base value at the top of the column to the left-- thus 0.89 = 7.36 ÷ 8.28.

The required steam-generating capacity of these boilers depends on their thermal efficiency and that of the distribution system, the pressure and condition of the steam to be generated, and the thermal efficiency of the directly fired equipment in use these days at Fort Leonard Wood. For estimation purposes, it is assumed that the latter is sixty-five percent and that the efficiency of modern boilers fired with solid fuel from an Energy Plantation (see Appendix B, section III) and the heat-distribution system is also about sixty-five percent. The steam generated is assumed to be saturated at 165 psia. If condensate is returned to the boilers at 212° Fahrenheit, the steam rate for each boiler at its design firing rate will be about 200,000 pounds of steam per hour (see Appendix E, section II.A.)

The erected cost of three field-erected boilers, each meeting these steam condition and rate requirements and equipped with moving grate and spreader stoker suitable for firing chipped deciduous plant material, is estimated to be about $11.8 million (Appendix E, section II.A.).

X.K.2. Precipitator Cost. For estimating the precipitator cost, it is assumed that the plant material as fired contains thirty percent moisture and that thirty percent excess combustion air is used. The temperature of the flue gas as it enters the precipitator is assumed to be 500° Fahrenheit. Under these conditions, the flue-gas volume per boiler will be about 132,000 cubic feet per minute.

On the assumption that a separate precipitator is used for each boiler, the estimated cost of three precipitators is about $900,000 (see Appendix E, section II.B.).

X.K.3. Steam-Distribution System. The buildings at Fort Leonard Wood are located in an approximately rectangular area about one and one-half miles wide by about two and a quarter miles long. The buildings are assumed to be distributed fairly uniformly in this area along eleven "streets" running the length of the rectangle. It is also assumed that the central heating plant can be located at the center of the rectangle and that it delivers its steam through two main headers, one running from the boiler in one direction across half the width of the rectangle, and the other running to the periphery of the rectangle across half its width in the opposite direction from the boiler. Eleven distribution lines emanate from each of the headers at right angles to them along the "streets". Each of these distribution lines carries one twenty-second of the steam. A tap line about fifty feet long connects each building to a distribution line. The diameters of the headers, and distribution and tap lines are chosen so that the steam velocity in each of them at design steam rate is about 200 feet per second.

The condensate return pipes are assumed to be in the same pattern as the steam lines. Their diameters are selected assuming the condensate flow rate is about ten feet per second. A one-pipe system, that is without condensate return, is also considered.

It is assumed that the distribution system is thermally insulated pipe encased in concrete and buried underground.

On the basis of these assumptions, the estimated installed cost of the distribution system with condensate return is about $11.4 million, and without condensate return about $10.7 million (see Appendix E, section II.C.).

The cost of alterations required in buildings has not been estimated in detail, but it should be at least $5,000 per building. This rough estimate has been included in the overall capital cost estimate for a central heating system.

X.K.4. Capital and Operating Costs. These costs are described in detail in Appendix E, section II.D. and are summarized here in Table XXII. The estimated manpower requirements are listed in Table XXIII. The relatively large number of maintenance people are required for maintenance of the district heating system.

In the estimates of capital cost, the entry for unestimated items is twenty-five percent of the estimated cost of the four items for which estimates have been made. Unestimated items include site preparation, buildings, fuel-handling and drying equipment, condensate pumps and engineering design.

For the annual operating costs, it is estimated that 180,000 dry tons of plant material will be required per year for the system with condensate return. Without condensate return, about 220,000 tons will be needed. Allowance for this difference in fuel requirements and for feedwater treatment are the major causes for the overall differences in estimated operating costs for the systems with and without condensate return. The provision for the cost of facilities replacement assumes that the useful service life of the entire system is twenty years.

X.L. Synthetic-Natural-Gas Production Plant.

X.L.1. Process Capacity. To provide the fuel required by the fixed facilities at Fort Leonard Wood with SNG, four plant-matter pretreatment and digestion trains (see section VIII.G.) will be needed. Three

TABLE XXII

ESTIMATED CAPITAL AND OPERATING COSTS FOR SOLID-FUELED CENTRAL HEATING SYSTEMS AT FORT LEONARD WOOD

Cost Element	Without Condensate Return	With Condensate Return
Capital Cost:		
Central boilers	$\$11.8 \times 10^6$	$\$11.8 \times 10^6$
Precipitators	0.9×10^6	0.9×10^6
Distribution system	10.7×10^6	11.4×10^6
Building alterations	3.7×10^6	3.7×10^6
Unestimated items	6.8×10^6	7.0×10^6
Total Estimated Capital Cost	$\$33.9 \times 10^6$	$\$34.9 \times 10^6$
Annual Operating Cost:		
Solid fuel (plant material at $12.65 per dry ton)	2.81×10^6	2.28×10^6
Electricity (6.53×10^6 kWh)	0.06×10^6	0.06×10^6
Boiler feedwater treatment	0.20×10^6	0.10×10^6
Operating labor	0.21×10^6	0.21×10^6
Maintenance labor	0.62×10^6	0.62×10^6
Supervision and clerical	0.14×10^6	0.14×10^6
Administration and general overhead	0.39×10^6	0.39×10^6
Operating supplies	0.06×10^6	0.06×10^6
Maintenance supplies	0.60×10^6	0.60×10^6
Facilities replacement cost	1.74×10^6	1.79×10^6
Total Estimated Annual Cost	$\$6.8 \times 10^6$	$\$6.3 \times 10^6$

trains, even if operated at full capacity all year, would produce only about ninety percent of the SNG requirement. The four trains will be served by a single gas purification train and fossil-fuel-fired boiler plant.

It is assumed that the SNG plant will be operated at a constant rate, and therefore that facilities are available for storing SNG at those times when demand for it is below the production rate (see section VIII.F.). It is also assumed that the gas mixture evolved from the anaerobic digester is approximately a fifty-fifty mixture of methane and carbon dioxide saturated with water vapor.

About 240,000 tons (dry basis) of plant material will be required every year, which is the equivalent of processing on the average about 660 dry tons of plant material per day. While the raw-material requirements are expressed in dry tons, the raw material as charged to the process neither needs to be, nor in fact should be, dry. Any moisture it contains will contribute to the make-up water requirement of the pretreatment and digestion train, which amounts to about 1.25 tons of water per oven-dry ton of plant material processed (see Figure D-V in Appendix D). There may be, however, a practical upper limit to the moisture content of the raw material, there being some evidence suggesting that the effectiveness of the grinding operation declines notably when the moisture content of the plant material is at or near its fresh-cut level. In any event, the moisture content of freshly harvested plant material will vary throughout the year. It will be at its highest level during the growing season and somewhat lower during the dormant period.

The SNG plant will be operated twenty-four hours per day seven days a week. Four work turns will therefore be required.

TABLE XXIII

ESTIMATED WORK FORCE REQUIREMENTS FOR SOLID-FUELED CENTRAL HEATING SYSTEMS AT FORT LEONARD WOOD

Skill Category	Number of People
Boiler tenders	8
Boiler helpers	8
Fuel handlers	4
Maintenance personnel	60
Supervision:	
superintendent	1
operating fore	1
maintenance foreman	1
shift foreman	4
clerk typist	1
Total work force	88

X.L.2. Energy Balance. About forty-four percent of the process steam required must be near saturation at about 400° Fahrenheit. This steam will be used for indirectly heating the steeping tank. Almost all the remainder of the steam will be used as a source of indirect heat for absorbent recovery in the carbon dioxide removal unit in the gas purification train. This steam should be near saturation at about 300° Fahrenheit.

For the reasons noted in section VIII.H., the steam will be generated at a high enough pressure and temperature (1,200 psia and 700° Fahrenheit) to allow it to be used effectively for generating electricity for shaft power before it is used for process heating purposes. It will be expanded in an extraction-back-pressure turbine which drives the generator. The extracted steam will be at 400° Fahrenheit, and the back-pressure steam at 300° Fahrenheit. The generator will provide about fifteen percent of the electricity required for the process, or enough to meet the requirements of the mixers on the anaerobic digesters and mixing tanks, the vacuum filters on which spent sludge from the digesters is dewatered, and the methane compressors in the gas purification train.

None of the process steam will be condensed for any purpose other than providing process heat. The condensate will be returned to the boiler under pressure at or near its boiling point.

The energy balance is discussed in considerable detail in Appendix D, section II.E.5., and is summarized in Table XXIV. It will be seen that the estimated energy efficiency of the process is about forty-nine percent, and that about thirty-seven percent more heating value is provided by the SNG produced than is consumed in fuels for producing the SNG.

TABLE XXIV

SUMMARY OF THE ENERGY BALANCE FOR AN SNG ENERGY PLANTATION SYSTEM FOR FORT LEONARD WOOD

Basis: one hour's operation of the SNG process

Energy Inputs:		
Fuel used by the boilers		73×10^6 Btu/hour
Primary fuel used for purchased electricity:		
total shaft power in the SNG process:	16,826 Hp.	
power supplied by electricity generated from boiler steam:	2,598 Hp.	
power from purchased electricity	14,228 Hp.	
primary fuel required to generated purchased electricity at 9,300 Btu per kWh		98×10^6 Btu/hour
Fuels used in Energy Plantation to produce plant material for one hour's operation of SNG process (27.4 dry tons)		7×10^6 Btu/hour
Total energy from fuels		178×10^6 Btu/hour
Fuel value of 27.4 tons of plant material		318×10^6 Btu/hour
Total energy input from fuels and raw material		496×10^6 Btu/hour
Energy Output:		
244,000 standard cubic feet of SNG		244×10^6 Btu/hour

Energy efficiency - (244/496) x 100: 49%

Ratio: fuel value in SNG produced to total energy input from fuels - (244/178): 1.37

X.L.3. Capital and Operating Costs for SNG Process. The estimated capital cost (Table XXV) has been approximately optimized by the choices made of process sequence for plant-material pretreatment (see section VIII.D.) and for gas purification (see section VIII.F.), and by the equipment capacities selected for the anaerobic digesters and spent-sludge vacuum filters. These considerations are described in considerable detail in section II.E. of Appendix D.

Reference to Table XXV indicates that the cost of the anaerobic digesters is about a third of the total estimated capital cost of the SNG production facility. The second largest element of capital cost is the attrition mills and their feeders and valves, which together account for almost a quarter of the total estimated cost.

The estimated annual operating costs and manpower requirements are summarized in Tables XXVI and XXVII, respectively. The operating costs have been approximately optimized by the selection of process sequences and equipment capacities previously mentioned in connection with the capital costs.

Not surprisingly, the largest single source of annual cost is the plant material used. It accounts for about thirty-five percent of the total annual cost. The second largest source of cost (seventeen percent) is replacement of worn-out equipment. This cost is estimated on the assumption that the average service life of the equipment in the facility is about twenty years. However, the probable service lives of certain of the equipment, particularly the attrition mill and compressors, are very likely to be considerably shorter than twenty years. The third most costly requirement is purchased electricity--eleven percent of the total estimated cost.

TABLE XXV

ESTIMATED APPROXIMATELY OPTIMIZED CAPITAL COST OF AN SNG PRODUCTION FACILITY FOR FORT LEONARD WOOD

(4 pretreatment and digestion trains)

Equipment and Associated Auxiliaries	Installed Cost
Pretreatment System:	
Metering feeders Rotary valves Disc attrition mills	$\$5.92 \times 10^6$
Steeping tanks	0.76×10^6
Heat exchangers	0.36×10^6
pH-adjustment tanks	0.36×10^6
Digestion System:	
Anaerobic digesters	8.52×10^6
Vacuum filters	3.04×10^6
Gas Purification System:	
Heat exchangers	0.04×10^6
Mixed-gas compressors	2.21×10^6
Benfield unit (CO_2 removal)	0.92×10^6
Heat exchangers	0.05×10^6
Methane compressors	0.63×10^6
Glycol dehydration unit	0.12×10^6
Boiler, Turbo-electric Generator and Steam Distribution System:	2.34×10^6
Total Estimated Capital Cost	$\$25.27 \times 10^6$

Together, these three sources of costs account for nearly two-thirds of the total operating cost. Their total cost is sensitive to the methane yield per unit weight of plant material and to the energy necessarily applied to the plant material in the attrition mill. It has been noted elsewhere that neither of these factors is well understood, although the impact of their variation within practically conceivable ranges can be estimated (see section XI.L.). This lack of understanding and the importance of these factors to the cost are part of the reasoning behind recommendation C.1.

X.M. Total Estimated Costs of Energy Plantation Systems for Fort Leonard Wood. The estimated capital and annual operating costs for the three Energy Plantation systems considered in sections X.K. and X.L. are summarized in Table XXVIII.

With reference to the two central heating systems, it will be seen that when allowance is made for the capital cost of the larger plantation required for the system without condensate return, the total estimated capital costs of the systems with and without condensate return are essentially the same--about $40 million in each case. However, the estimated annual operating cost of the system with condensate return is lower than for the system without return. Therefore, if a central heating system fired with solid fuel is to be installed at Fort Leonard Wood, a system with condensate return should be chosen.

The operating cost of the central heating system is estimated to be about $3.04 per million Btu of fuel presently used at the fort (about 2.08 trillion Btu per year-see Table VIII). This cost includes the cost of burning the plantation fuel and delivering the useful heat so produced to the hot side of the interfaces through which it is delivered to the air for space heating and the water used as hot water in the

TABLE XXVI

ESTIMATED APPROXIMATELY OPTIMIZED ANNUAL OPERATING COST OF AN SNG PRODUCTION FACILITY FOR FORT LEONARD WOOD

(4 treatment and digestion trains)

(annual production of SNG: 2.14×10^9 standard cubic feet)

Cost Element	Estimated Annual Cost
1. Plant material (240,000 tons at $11.66/ton)	$\$2.80 \times 10^6$
2. Ammonia for fixed nitrogen and digester pH control	0.52×10^6
3. Boiler fuel (coal at $\$0.417/10^6$ Btu)	0.31×10^6
4. Purchased electricity ($0.0098/kWh)	0.91×10^6
5. Operating labor (68 people at $5/hour)	0.71×10^6
6. Maintenance labor (14 people at $5/hour)	0.51×10^6
7. Supervision and clerical (11 people at $14,000/yr)	0.16×10^6
8. Admin. & gen'l overhead (40% of 5+6+7)	0.41×10^6
9. Operating supplies (30% of 5)	0.21×10^6
10. Maintenance supplies (2% of capital cost)	0.51×10^6
11. Equipment replacement(5% of capital & start-up costs)	1.33×10^6
Total Estimated Annual Operating Cost	$\$8.00 \times 10^6$
Cost of SNG Produced	$\$3.74/10^3$ SCF

mess halls, laundries, for personal use and the like. This cost is competitive with, and in all probability less than, the present equivalent cost for those installations in which oil is used these days at Fort Leonard Wood. This is an important point, because oil accounts for more than two-thirds of the fuel used at the fort (see Table VIII).

The assertion with respect to the competitiveness of the annual operating cost of a central heating system fired with solid fuel from an Energy Plantation made in the previous paragraph, is based on the following consideration. Heavy and light fuel oils delivered to Fort Leonard Wood are almost certainly costing the fort at least two dollars per million Btu these days and very likely will become more expensive, and possibly much more so, in the next few years. Moreover, to make these fuel costs comparable with the $3.04 per million Btu cost estimated for the solid-fueled central heating system, the costs of distributing fuel oils to their points of use at the fort, of burning them, and of maintaining the equipment in which they are burned must be added to the cost of fuel oils as delivered to the base. These conversion costs are certainly at least between fifty cents and one dollar per million Btu. Thus, the present cost of heat from fuel oil delivered to the hot side of the interfaces through which the heat is delivered for use is at least two and a half to three dollars per million Btu in the fuel oil fired.

The cost of solid fuel from an Energy Plantation system is unlikely to increase very much for many years to come, in part because the cost is insensitive to the cost of liquid fossil fuels since little of them is used in the plantation (see section X.J. and Table XIX). The cost is also unlikely to increase very much over the next few years because Energy Plantation operation is now only at the foot of its learning

TABLE XXVII

ESTIMATED WORK FORCE REQUIREMENTS FOR AN SNG PRODUCTION FACILITY FOR FORT LEONARD WOOD

Skill Category	Number of People
Supervision and clerical:	
Manager	1
Operating foremen (1 per work turn)	4
Maintenance foreman	1
Office staff (1 per work turn + 1 five days per week)	5
Operating Personnel:	
Pretreatment operators (4 per work turn)	16
Pretreatment helpers (4 " " ")	16
Digester and vacuum-filter operators (4 per work turn)	16
Gas purification train operators (1 per work turn)	4
Gas purification train helpers (1 " " ")	4
Truck terminal helpers (5 days per week)	2
Laboratory technicians (5 " " ")	2
Maintenance Personnel	
Journeymen (1 per work turn + 3 five days per week)	7
Helpers (1 per work turn + 3 five days per week)	7
Boiler and Turbo-generator Personnel	
Operators (1 per work turn)	4
Helpers (1 per work turn)	4
Total Work Force	93

curve, and therefore, the operating economies which are bound to be achieved fairly quickly after operation is started have not yet found their way into the system.

Comparison of the annual operating cost shown in Table XXVIII of the SNG system as estimated on the basis of the state-of-the-art for producing SNG (particularly the fifty-fifty ratio assumed for the methane and carbon dioxide in the gas mixture evolved from the anaerobic digesters) with the cost of using solid fuel in a central heating system is unfavorable. However, after allowance is made for the likely improvements in the art discussed in connection with the sensitivity analysis of the estimates for Fort Benning in section XI.L.,it is quite possible that the annual operating cost of the SNG system at Fort Leonard Wood will be reduced to about $6.5 million per year and the capital cost to about $23 million. On this basis, the costs of the SNG Energy Plantation system would be far more attractive than either of the central heating systems, and the cost of gas would be favorable indeed in comparison with the estimated costs being announced these days for SNG from coal. Moreover, at an annual operating cost of about $3.10 per million Btu for SNG produced, the SNG cost is very likely to be competitive with the present cost of fuel oil (the major fuel at Fort Leonard Wood) delivered to its points of use on the base.

These various conclusions are part of the basis for recommendation A. They are also an element in the basis for recommendation C.1.,because they highlight rather clearly the worthiness of finding out what the methane production rate and necessary process parameters are actually likely to be for producing SNG from raw material produced in an Energy Plantation.

TABLE XXVIII

TOTAL ESTIMATED COSTS OF ENERGY PLANTATION SYSTEMS FOR FORT LEONARD WOOD

	Central Heating System		
	With Condensate Return	Without Condensate Return	SNG System
Operating Factors:			
Plant Material - dry tons per year	180,000	220,000	240,000
Plantation area at 8.3 dry tons per acre-year	21,700	26,500	29,000
Capital Costs:			
Plantation at 8.3 dry tons per acre-year	$\$5.4\times10^{6}$	$\$6.6\times10^{6}$	$\$7.5\times10^{6}$
Central heating system	34.9×10^{6}	33.9×10^{6}	
SNG production system			25.3×10^{6}
Totals	$\$40.3\times10^{6}$	$\$40.5\times10^{6}$	$\$32.8\times10^{6}$
Capital cost per 10^6 Btu per year at present fuel consumption rate:	19.40	19.40	15.80
Operating Costs:			
Central heating system	$\$6.3\times10^{6}$	$\$6.8\times10^{6}$	
SNG production system			$\$8.0\times10^{6}$
Operating cost per 10^6 Btu at present fuel consumption rate:	\$3.04	\$3.30	\$3.74
Operating cost per 1000 SCF of SNG produced			\$3.74

XI. AN ENERGY PLANTATION SYSTEM FOR FORT BENNING

XI.A. Design Considerations. In fiscal year 1973, 2.5×10^{12} Btu of fuel were used in fixed installations at Fort Benning. The fuel types used and seasonality in total fuels consumption are shown in tables VII and IX. The 1973 fuel consumption will be used as the design basis for Energy Plantation systems for Fort Benning.

At a production rate of 4.5 standard cubic feet per pound of oven-dry plant matter, a plantation supplying the raw material to produce enough SNG to meet all the fuel needs for stationary facilities on the base will have to generate about 280,000 oven-dry tons of harvestable plant matter per year. If the fuel needs are supplied as solid fuel, the capacity of the plantation will have to be about 220,000 oven-dry tons of plant matter per year.

Fort Benning is located in west central Georgia at an elevation of about 385 feet. Its climate is typical of the South--mild winters, hot summers with temperatures exceeding 90° Fahrenheit on many days. The frost-free period is about 260 days, and the annual normal temperature is about 65° Fahrenheit. The annual normal rainfall is about fifty inches with a significant amount falling during the growing season. Although the rainfall during the growing season is characterized by large downpours, generally speaking the distribution of rainfall is more favorable than around Fort Leonard Wood. The two main types of soils considered at Fort Benning for Energy Plantations, namely sandy loam uplands and Ochlocknee bottomlands, are porous enough to absorb significant amounts of moisture and thus probably act as reservoirs of moisture to sustain plant growth during the dry period occurring between rainfalls. It is thus expected that the climate-moisture-soil interrelation in the Fort Benning area is more favorable for deciduous plant growth than is the case at Fort Leonard Wood. A discussion of these climate factors is to be found in Appendices G and H.

The total area of the land having soil types considered satisfactory for plantations is about 60,000 acres. The fraction of this land which could be used for plantations without interfering with troop training and other operations is unknown. Detailed information on land use and land availability on the base was not available.

A summary of the main estimates for plantation systems at Fort Benning is compiled in Table XXIX.

XI.B. Selection of Plant Species. The growth season for warm-season grasses is limited to the period of the year when the average temperature is 55° to 60° Fahrenheit and over. In the Fort Benning area, such temperature conditions are only expected on the average from April to September. As a result, and although high sustained yields perhaps compatible with Energy Plantation requirements can be achieved, the enormous storage problem associated with providing warm-season grass material for use during the winter has caused warm-season grass species to be ruled from consideration for Fort Benning.

The deciduous species selected for Fort Benning are:

- for the sandy loam upland sites--varieties of hybrid poplar, eastern and Missouri cottonwood, sycamore, and perhaps European black alder,
- for the Ochlocknee bottomland soils, varieties of hybrid poplars, eastern cottonwood and sycamore.

This selection has been established on the basis of data collected during visits in Pennsylvania, Iowa, Kansas and Georgia and from various experts, including several who are familiar with the Fort Benning area.

XI.C. Estimated Plant-Material Production Rates and Plantation Area Requirements. Expected sustained annual yields have been determined for the species of interest on the basis of the tree growth simulation model and optimization procedure described in Appendix C.

It is estimated that the average annual sustained yield from deciduous species preferred for Fort Benning is about 8.8 oven-dry tons per acre-year. The expected range for the sustained yield extends from about 7.8 to about 9.8 oven-dry tons per acre-year. The planting density-harvest schedule combination leading to the estimated average sustained yield is four square feet per plant at planting (about 11,000 plants per acre), first harvest one year after planting, subsequent harvests at two-year intervals and a total of six harvests before replanting the stand. As discussed in section X.C.,an eleventh of the plantation will be replanted every year to avoid interruption in the regular availability of harvestable plant material. The planting stock needed is grown on the plantation itself. Taking these requirements and the predicted average yield of 8.8 oven-dry tons per acre-year into account, an area of about 32,000 acres is needed to supply the raw material for SNG production, while an area of about 25,000 acres is necessary if solid fuel is to be produced.

A sensitivity analysis shows that if land availability permits, and more specifically, if about fifteen percent more land than mentioned in the preceding paragraph can be made available, a planting density of eight

TABLE XXIX

SUMMARY OF PLANTATION SYSTEM ESTIMATES FOR FORT BENNING

Estimated Factor	Units	For Solid Fuel			For SNG		
		Low	Probable	High	Low	Probable	High
Average Annual Sustained Plant-Material Yield	Dry tons per Acre-year	7.8	8.8	9.8	7.8	8.8	9.8
Plant Material Required	Dry tons per year	220,000	220,000	220,000	280,000	280,000	280,000
Required Plantation Area	Acres	28,200	25,000	22,400	35,900	31,800	28,600
Plantation:							
-Planting density	Sq. feet per plant	4	4	4	4	4	4
-Age at first harvest	Years	1	1	1	1	1	1
-Interval between harvests	Years	2	2	2	2	2	2
-Harvests per planting		6	6	6	6	6	6
-Establishment Cost	$	6.6×10^6	6.3×10^6	6.0×10^6	8.8×10^6	8.4×10^6	8.1×10^6
-*Annual operating cost*	*$/year*	2.8×10^6	2.7×10^6	2.7×10^6	3.2×10^6	3.2×10^6	3.1×10^6
-Cost of plant material	$ per dry ton	12.70	12.50	12.30	11.50	11.30	11.10
-Cost of plant material	$ per 10^6 Btu	1.09	1.08	1.06	0.99	0.97	0.96
-Work force:							
full-time	People		95			147	
part-time	Man-months per year		204			258	
Central Heating or SNG Systems:							
-Boilers or pretreatment-digestion trains			4			5	
-Steam-generating capacity	lb per hour		640,000				
-SNG production capacity	SCF per day		-			8.9×10^6	
-Plantation Establishment Cost	$		6.3×10^6			8.4×10^6	
-Cap. Cost of heating plant and distribution	$		42.8×10^6			-	

TABLE XXIX (continued)

SUMMARY OF PLANTATION ESTIMATES FOR FORT BENNING

Estimated Factor	Units	For Solid Fuel			For SNG		
		Low	Probable	High	Low	Probable	High
-Capital cost of SNG facility	$		-			31.3 x 10^6	
-Total capital cost	$		49.1 x 10^6			39.7 x 10^6	
-Cost per 10^6 Btu per year at present fuel use rate	$/$10^6$ Btu /year		19.50			15.80	
-Annual operating cost	$/year		7.4 x 10^6			10.6 x 10^6	
-Annual cost per 10^6 Btu at present fuel use rate	$/year		2.90			-	
-SNG cost per 10^6 Btu	$/$10^6$ Btu		-			4.24	
-Work force							
Plantation-full-time	people		95			147	
Central Heating or SNG - full-time	people		98			108	
Total full-time	people		193			255	
Part-time	man months/year		204			258	

square feet per plant (about 5500 plants per acre) with a first harvest at one year and subsequent harvests at three-year intervals produces yields only slightly lower than those estimated for the four-square-foot planting density but offers the possibility of reducing the cost of plant-material production.

XI.D. Plantation Operation. Plantation operation at Fort Benning will be similar to that described for Fort Leonard Wood in section X.D. The only significant difference is that at Fort Benning the replanting period extends from early March to the end of June, a circumstance which allows more flexibility in field-machinery assignment than is possible at Fort Leonard Wood.

XI.E. Plantation Establishment. For the harvest schedule proposed for Fort Benning, about three years will be needed to establish the plantation. The proposed schedule of operations during the establishment period is therefore essentially the same as that described for Fort Leonard Wood (see section X.E.).

XI.F. Plantation Organization. The analysis in Appendix F, section V.B.1., indicates that for effective use of field machinery, transport equipment and manpower, the plantation should be divided into compact land units having a production capacity of about 40,000 dry tons of plant material per year. At the average annual yield of 8.8 dry tons per acre-year expected for Fort Benning, each of these units will have an area of about 4,500 acres.

The supervisory group for plantations at Fort Benning will consist of five persons, irrespective of whether solid fuel or SNG raw material is being produced. The motor pool, which will also be responsible for maintenance of field and transport equipment, will require more people and a larger equipment reserve at an SNG plantation than at a solid-fuel plantation. Supervision and maintenance will be housed in the same building. The estimated staffing and reserve equipment requirements for these two functions are summarized in Table XXX. The requirements are not affected by the yield per acre-year in the plantation.

The total work force, by skill, estimated to be required for plantations growing solid fuel and raw material for SNG at Fort Benning are shown in Table XXXI. Also shown are the estimated pay rates by skill level.

XI.G. Cost of Plantation Establishment. The major sources of cost incurred in establishing a plantation at Fort Benning are similar to those described for Fort Leonard Wood in section X.G. Moreover, as has been found to be the case for Fort Leonard Wood, the estimated cost of plantation establishment at Fort Benning is also affected only in a relatively minor way by the expected average annual sustained yield of plant material at the plantation (see Table XXIX).

The major sources of estimated cost for plantations at Fort Benning in which the average annual yield is at the probable level (8.8 dry tons per acre-year) are shown in Table XXXII. The genesis of these estimated costs is developed in Appendix G, section V.B.3.

The pattern of estimated costs at Fort Benning is seen to be similar to that for Fort Leonard Wood. The largest single source of cost, for instance, is the cost of equipment and facilities, and the second largest cost (about a third of the total) is for clones and their planting.

XI.H. Plantation Operating Costs. It has been noted in the discussion of plantation operating costs at Fort Leonard Wood (see section X.H.) that the annual cost is almost independent of the annual average yield of plant material from the plantation in the range of yields under consideration. The same conclusion is reached for plantations at Fort Benning (see Table XXIX).

The estimated costs of plantation operation have been summarized in two ways. The first of these, shown in Table XXXIII, is by the original elements of cost such as manpower (based on the pay rates shown in Table XXXI), fuels, spare parts, supplies and so forth. These estimates lead to the conclusion that the probable costs of plant material grown for solid fuel and for SNG raw material at Fort Benning are about $12.50 and $11.20 per dry ton, respectively. These costs are slightly lower than the corresponding ones for Fort Leonard Wood. The costs at Fort Benning are the equivalent of about $1.08 and $0.97 per million Btu of useful fuel value (the lower heating value) from plant material which is approximately air-dry.

The estimated annual operating costs at Fort Benning have also been examined from the point of view of the major plantation operations. For this purpose, the costs of harvesting, plant-material delivery and so forth are expressed as percentages of the estimated total annual operating cost (see Table XXXIV). Plant-material delivery and sludge handling taken as a group, and harvesting are the two most costly operations, a finding which is not entirely surprising in view of the similar conclusion reached for Fort Leonard Wood. For Fort Benning, it is estimated that

TABLE XXX

ESTIMATED MANPOWER AND EQUIPMENT REQUIREMENTS FOR SUPERVISION AND MOTOR POOL FOR PLANTATIONS AT FORT BENNING

Personnel	Equipment	Personnel: For Solid Fuel	Personnel: For SNG Raw Material
Supervision:			
General foreman	1 pickup truck	1	1
Horticulturist	1 pickup truck	1	1
Motor pool foreman	1 pickup truck	1	1
Field foreman	1 pickup truck	1	1
Secretary-dispatcher		1	1
Motor Pool:			
Mechanics	2 pickup trucks	5	
Mechanics	3 pickup trucks		7

Reserve Equipment Assigned to the Motor Pool

	For Solid Fuel	For SNG Raw Material
Harvesters	3	3
Chip trucks	3	3
Chip dump wagons	5	6
Sludge trucks	-	3
Tractors	3	3

the cost of these operations amounts to fifty-two percent of the total annual operating cost in the case of plant material grown for solid fuel and seventy-one percent when raw material for SNG production is to be grown.

XI.I. Energy Balance for Energy Plantations. The estimated fuel requirements for plantation operation per ton of plant material delivered five miles off the plantation site are about 220,000 and 270,000 Btu for solid fuel and SNG raw material, respectively (see Appendix G, section V.B.3.). These requirements are about two percent of the useful fuel value (lower heating value) of the plant material when it is approximately air dry. These requirements suggest, even after making liberal allowance for any errors in the estimated fuel requirements, that an Energy Plantation will deliver *twenty-five or more times as much* fuel value as is consumed in the plantation as gasoline and diesel fuel.

XI.J. Sensitivity Analysis. The general conclusions from the sensitivity analysis performed for Fort Leonard Wood (section X.I.) and summarized in Figure II are valid for Fort Benning, also. Analysis specifically for Fort Benning shows that, if the planting density is decreased from one plant per four square feet to one every eight square feet, and if the harvest schedule is to take the first harvest when the stand is one year old and subsequent harvests at three-year intervals, the cost of plant material can be reduced to about $11.50 and $10.40 per dry ton for solid fuel and SNG raw material, respectively.

However, to achieve these plant-material costs, the plantation area must be increased from the absolute minimum area represented by the four square feet per plant and the associated harvest schedule by about ten percent, the equivalent of about three thousand acres.

TABLE XXXI

ESTIMATED PERSONNEL REQUIREMENTS AND PAY RATES FOR PLANTATIONS AT FORT BENNING

Skill Level	Pay Rates $ Per Year	Personnel Requirements For Solid Fuel	Personnel Requirements For SNG Raw Material
General foreman	22,000	1	1
Horticulturist	18,000	1	1
Motor pool foreman	15,000	1	1
Field foreman	11,000	1	1
Secretary-dispatcher	6,500	1	1
Mechanics	10,000	6	7
Harvester operators	9,100	28	35
Tractor operators	6,500	27	35
Crawler operators	6,900	2	2
Truck drivers	7,500	27	63
Totals		95	147
Unskilled personnel part-time	$450/month	204	258

XI.K. Solid-Fueled Central Heating System. The system design and the estimated costs for a solid-fueled central heating system for Fort Benning are derived in a manner which is analogous to the procedure used for Fort Leonard Wood.

XI.K.1. Boiler Capacity and Cost. The normally expected heat load (as measured by the fuel consumption rate) at Fort Benning in the summertime is about 132 billion Btu per month (see Table A-XIV in Appendix A) or 180 million Btu per hour. With the same assumptions which were used for Fort Leonard Wood, the firing capacity of the central heating plant should be about 540 million Btu per month to accommodate this base load.

The highest monthly fuel consumption rate in wintertime is about 353 billion Btu per month or 490 million Btu per hour. The space heating load is thus about 310 million Btu per hour. The required capacity for space heating is this amount plus fifty percent for reserve, or about 470 million Btu per hour.

The total required capacity is 1,010 million Btu per hour, of which about half is needed for the base summertime load. Four boilers can handle this total load, each with a firing capacity of about 250 million Btu per hour. With the same assumptions of system efficiency and steam conditions as for Fort Leonard Wood, each boiler at Fort Benning will deliver about 160,000 pounds of steam per hour.

The erected cost of these boilers is estimated to be about $13.4 million (see Appendix E, section III.A.).

TABLE XXXII

MAJOR ELEMENTS IN THE ESTIMATED COST OF PLANTATION ESTABLISHMENT AT FORT BENNING

Average annual production rate: 8.8 dry tons per acre-year
(in thousands of dollars, except as noted)

Source of Cost	Plant-Material Production For: Solid Fuel	Plant-Material Production For: SNG Raw Material
Land clearing and preparation	300	380
Lime and fertilizer	200	260
Lime and fertilizer application	140	180
Clones purchased	250	320
Clone production	1,010	1,280
Planting	830	1,060
Cultivation	120	160
Harvesting	180	240
Motor pool	80	100
Supervision	280	280
Total	3,390	4,260
Equipment and Facilities	2,950	4,150
Establishment Cost	$\$6.3 \times 10^6$	$\$8.4 \times 10^6$

XI.K.2. Precipitator Cost. The volume of flue gas generated by each boiler operating at capacity should be about 111,000 cubic feet per minute.

On the assumption that a separate precipitator is used for each pair of boilers, the estimated cost of two precipitators for a central heating plant at Fort Benning is $900,000 (see Appendix E, section III.B.).

XI.K.3. Steam-Distribution System. The same type of idealized model of the layout of the buildings was set up for Fort Benning as was used for Fort Leonard Wood. Most of the buildings at Fort Benning are in an area which is very roughly a rectangle about one and two-thirds miles wide by two and one-third miles long. The buildings are assumed to be distributed uniformly in this area along fourteen "streets" running the length of the rectangle. The boiler plant is assumed to be located in the center of the rectangle with two main steam headers, each running from the boiler to the periphery of the rectangle in the direction of its width. Each header carries steam to fourteen distribution lines, which run parallel to the streets. Each distribution line carries one-twenty-eighth of the steam.

The same pipe diameters for the various lines are assumed for Fort Benning as for Fort Leonard Wood, since the maximum boiler capacities are about the same at the two training centers.

On the basis of these assumptions, the estimated installed cost of the distribution system with condensate return is about $15.0 million, and about $14.0 million without condensate recovery (see Appendix E, section III.C.).

TABLE XXXIII

ESTIMATED COSTS OF PLANTATION OPERATION AT FORT BENNING BY MAJOR ELEMENTS OF COST

Average annual production rate: 8.8 dry tons per acre-year
(in thousands of dollars, except as noted)

Cost Element	Plant-Material Production For: Solid Fuel	Plant-Material Production For: SNG Raw Material
Payroll		
Field personnel	688	1,052
Mechanics	60	70
Supervision and clerical	73	73
Administration and general overhead	180	261
Equipment replacement	529	748
Equipment spare parts	313	411
Fuel	131	224
Plantation maintenance	100	127
Fertilizer	516	-
Lime	68	87
Pesticides	34	43
Misc. supplies	43	55
Total cost	$2.7 x 10^6$	$3.2 x 10^6$
Cost per dry ton of plant material harvested	$12.50	$11.20

XI.K.4. Capital and Operating Costs. These costs are described in detail in Appendix E, section III.D., and are summarized in Table XXXV. The operating costs are based on the same assumptions as used for the operating costs for Fort Leonard Wood. The manpower requirements for Fort Benning are listed in Table XXXVI. The only difference between the manpower required for Fort Benning and that for Fort Leonard Wood is that more maintenance people are required because of the larger investment to maintain.

XI.L. Synthetic-Natural-Gas Production Plant. The SNG production plant for Fort Benning differs only in size and amount of plant material processed and gas produced, from the plant for Fort Leonard Wood. The operating costs are somewhat different, because of the difference in the cost of the plant raw material--due to the different scale of operation--and the higher power and fuel costs at Fort Benning. The power and fuel costs at Fort Benning are more generally representative of these costs these days across the country than are those prevailing at present in the Fort Leonard Wood area.

A sensitivity analysis has been done on the capital and operating costs for the SNG production plant at Fort Benning for practically conceivable ranges in the key process variables. The results show how these costs can be decreased by certain improvements in the key variables.

XI.L.1. Process Capacity. To provide the fuel required by the fixed facilities at Fort Benning with SNG, five plant-matter pretreatment and digestion trains (see section VIII.G.) will be needed. To satisfy the present gas needs at Fort Benning, a five-train plant will be operated at an average of only seventy-seven percent of capacity throughout the year. However, some downtime must be expected and allowed for in the design of the plant, and a four-train plant would have to be operated

TABLE XXIV

ESTIMATED COSTS OF MAJOR PLANTATION OPERATIONS AS PERCENTAGES OF TOTAL PLANTATION OPERATING COST

	Plant-Material Production For:	
	Solid Fuel	SNG Raw Material
Harvesting	31	34
Plant-material delivery to point of use	21	24
Fertilizer	19	-
Sludge return to the land	-	13
All other field operations	13	12
Supervision	4	4
Clone production	3	4
Motor pool	5	5
Plantation maintenance	4	4
	100%	100%

at ninety-seven percent of capacity in order to meet the fuels requirement at Fort Benning, which is an unrealistically high on-stream factor.

About 280,000 tons (dry basis) of plant material will be required every year, which is the equivalent of processing on the average about 767 dry tons of plant material per day.

XI.L.2. Energy Balance. The energy balance for the plant at Fort Benning is essentially the same as for the plant at Fort Leonard Wood; only the absolute magnitude of the quantities of energy are changed in proportion to the scale of operations. The quantities of energy involved in the SNG plant at Fort Benning are summarized in Table XXXVII.

XI.L.3. Capital and Operating Costs for SNG Process. The estimated approximately optimized capital cost for the SNG production facility at Fort Benning is shown in Table XXXVIII.

The estimated annual operating cost and manpower requirements are summarized in Tables XXXIX and XL, respectively. The largest single source of cost is the plant material used, as it is at Fort Leonard Wood. However, the cost of purchased electricity is the second largest cost at Fort Benning rather than the third as it is at Fort Leonard Wood, because of the higher cost per kilowatt-hour at Fort Benning. The cost of equipment replacement is the third largest cost. These three sources of cost together again account for about two-thirds of the total operating cost.

TABLE XXXV

ESTIMATED CAPITAL AND OPERATING COSTS FOR SOLID-FUELED CENTRAL HEATING SYSTEMS AT FORT BENNING

Cost Element	Without Condensate Return	With Condensate Return
Capital Cost:		
Central boilers	$ 13.4 x 10^6	$ 13.4 x 10^6
Precipitators	0.9 x 10^6	0.9 x 10^6
Distribution system	14.0 x 10^6	15.0 x 10^6
Building Alterations	5.0 x 10^6	5.0 x 10^6
Unestimated items	8.3 x 10^6	8.6 x 10^6
Total Estimated Capital Cost	$ 41.5 x 10^6	$ 42.8 x 10^6
Annual Operating Cost:		
Solid fuel (plant material at $12.47 per dry ton)	$ 3.33 x 10^6	$ 2.69 x 10^6
Electricity (6.53x10^6 kWh)	0.12 x 10^6	0.12 x 10^6
Boiler feedwater treatment	0.24 x 10^6	0.12 x 10^6
Operating labor	0.21 x 10^6	0.21 x 10^6
Maintenance labor	0.73 x 10^6	0.73 x 10^6
Supervision and clerical	0.14 x 10^6	0.14 x 10^6
Admin. and general overhead	0.43 x 10^6	0.43 x 10^6
Operating supplies	0.06 x 10^6	0.06 x 10^6
Maintenance supplies	0.70 x 10^6	0.70 x 10^6
Facilities replacement cost	2.14 x 10^6	2.19 x 10^6
Total Estimated Annual Cost	$ 8.1 x 10^6	$ 7.4 x 10^6

XI.L.4. <u>Sensitivity Analysis of Capital and Operating Costs</u>. It is noted in section VIII and in Appendix D that various parameters which presently are not known very precisely have a significant effect on the performance and hence the design of the SNG production process. Because these parameters thus also have a significant impact on the capital and operating costs of the process, there is a good possibility for decreasing these costs by performing the proper experiments to define these variables and to learn how to improve them. These influential parameters are the required energy for grinding, retention time in the digesters, allowable solids content of the feed slurry, solubilization of woody material during steeping and the ratio of methane to carbon dioxide in the digester off-gas.

The impact of practically conceivable changes in these influential variables on capital and operating costs has been assessed for the SNG production plant at Fort Benning by a sensitivity analysis. This analysis is summarized in Table XLI. Listed in the table are the five basic parameters plus the cost of plant material and the case in which the benefits of all of these factors are combined. Shown in the table are the presently assumed value for the parameter, a realistically possible improved value, the particular costs influenced and the magnitude of the influence, and the overall resultant capital cost and cost of gas.

The energy required for grinding, the first parameter in the table, influences mainly the cost of purchased electricity, which is, however, the second largest source of annual cost at Fort Benning.

The retention time in the digesters, allowable solids content of the slurry, and solubilization of woody material as a result of steeping, all mainly influence the capital cost of the digesters, which is the largest single source of capital cost.

TABLE XXXVI

ESTIMATED WORK FORCE REQUIREMENTS FOR SOLID-FUELED CENTRAL HEATING SYSTEMS AT FORT BENNING

Skill Category	Number of People
Boiler tenders	8
Boiler helpers	8
Fuel handlers	4
Maintenance personnel	70
Supervision:	
Superintendent	1
Operating foreman	1
Maintenance foreman	1
Shift foremen	4
Clerk typist	1
Total Work Force	98

The split between methane and carbon dioxide in the effluent gas from the digester is an important parameter. If the gas is actually sixty percent methane, rather than only fifty, the amount of SNG needed at Fort Benning can be produced with a four-train processing facility, which lowers the required capital cost significantly.

With the combined benefits of the practically conceivable best values of the influential parameters plus an improvement in the cost of the raw plant material, the capital cost of an SNG production plant at Fort Benning is decreased by about a third, from $31.2 million to $21.5 million. The cost of gas is decreased by about seventeen percent from $4.24 to $3.51 per thousand standard cubic feet.

This sensitivity analysis shows that it should be possible to lower the estimated capital and operating costs of an SNG production facility at Fort Benning. This can be done by defining more precisly those parameters which have been shown to have the most influence on the most important elements of cost. This finding is the basis for recommendation C.1.

XI.M. Total Estimated Costs of Energy Plantation Systems for Fort Benning. The estimated capital and annual operating costs for the three Energy Plantation systems considered in section XI.K. and XI.L. are summarized in Table XLII.

With reference to the two central heating systems, the preferred system is the one with condensate return. Just as is the case with Fort Leonard Wood, the increased capital cost of the condensate-return system is just offset by the lower plantation cost, and the annual cost of the system with condensate return is lower than that of the system without.

TABLE XXXVII

SUMMARY OF THE ENERGY BALANCE FOR AN SNG ENERGY PLANTATION SYSTEM FOR FORT BENNING

Energy Inputs:		
Fuel used by the boiler		85×10^6 Btu/hour
Primary fuel used for purchased electricity:		
total shaft power in the SNG process:	19,653 Hp.	
power supplied by electricity generated from boiler steam:	3,035 Hp.	
power from purchased electricity:	16,618 Hp.	
primary fuel required to generate purchased electricity at 9,300 Btu per kWh		115×10^6 Btu/hour
Fuels used in Energy Plantation to produce plant material for one hour's operation of SNG process (32.0 dry tons)		8×10^6 Btu/hour
Total energy from fuels		208×10^6 Btu/hour
Fuel value of 32.0 tons of plant material		371×10^6 Btu/hour
Total energy input from fuels and raw material		579×10^6 Btu/hour
Energy Output:		
285,000 standard cubic feet of SNG		285×10^6 Btu/hour

Energy efficiency - (285/579) x 100:	49%
Ratio: fuel value in SNG produced to total energy input from fuels - (285/208):	1.37

Fuel oil is not presently used very much at Fort Benning (see Table VII); only about eight percent of the 2.51 trillion Btu per year required at Fort Benning is used in the form of fuel oil. However, the discussion of the cost of using solid fuel from an Energy Plantation compared with the cost of using fuel oil in section X.M. applies to Fort Benning as well as to Fort Leonard Wood. The growing shortage of natural gas is likely to force Fort Benning to convert to an alternative fuel, and the cost comparison discussed in section X.M. indicates that it would be better for Fort Benning to convert to solid fuel than to fuel oil, which is also likely to become increasingly expensive. Added capital costs would be incurred also to convert Benning to the use of fuel oil.

The comparison of the cost of solid fuel with the cost of SNG as estimated on the basis of the state-of-the-art is even more unfavorable to SNG than was the case with Fort Leonard Wood. However, the sensitivity analysis of the SNG costs indicates that there is potential for considerable improvement in these costs. In particular, the cost of SNG from plant material grown on Energy Plantations is certainly favorable in comparison with the estimated costs for SNG from coal.

Whether the cost of SNG can be made to be comparable with the cost of solid fuel from an Energy Plantation on an Army base depends on finding precise values for the influential process parameters, which is the basis for recommendation C.1.

TABLE XXXVIII

ESTIMATED APPROXIMATELY OPTIMIZED CAPITAL COST OF AN SNG PRODUCTION FACILITY FOR FORT BENNING

(5 pretreatment and digestion trains)

Equipment and Associated Auxiliaries	Installed Cost
Pretreatment System:	
Metering feeders Rotary valves Disc attrition mills	$ 7.40×10^6
Steeping tanks	0.95×10^6
Heat exchangers	0.45×10^6
pH-adjustment tanks	0.45×10^6
Digestion System:	
Anaerobic digesters	10.65×10^6
Vacuum filters	3.80×10^6
Gas Purification System:	
Heat exchangers	0.05×10^6
Mixed-gas compressors	2.66×10^6
Benfield unit (CO_2 removal)	1.08×10^6
Heat exchangers	0.06×10^6
Methane compressors	0.76×10^6
Glycol dehydration unit	0.14×10^6
Boiler, Turbo-electric Generator and Steam-Distribution System:	2.80×10^6
Total Estimated Capital Cost	$ 31.25×10^6

TABLE XXXIX

ESTIMATED APPROXIMATELY OPTIMIZED ANNUAL OPERATING COST OF AN SNG PRODUCTION FACILITY FOR FORT BENNING

(5 treatment and digestion trains)

(annual production of SNG: 2.49×10^9 standard cubic feet)

	Cost Element	Estimated Annual Cost
1.	Plant material (280,000 tons at $11.26/ton)	$ 3.15×10^6
2.	Ammonia for fixed nitrogen and digester pH control	0.61×10^6
3.	Boiler fuel (coal at $0.891/$10^6$ Btu)	0.67×10^6
4.	Purchased electricity ($0.0183/kWh)	1.98×10^6
5.	Operating labor (81 people at $5/hour)	0.84×10^6
6.	Maintenance labor (16 people at $5/hour)	0.17×10^6
7.	Supervision and clerical (11 people at $14,100/year)	0.16×10^6
8.	Administration and general overhead (40% of 5+6+7)	0.46×10^6
9.	Operating supplies (30% of 5)	0.25×10^6
10.	Maintenance supplies (2% of capital cost)	0.62×10^6
11.	Equipment replacement (5% of capital and start-up costs)	1.65×10^6
	Total Estimated Annual Operating Cost	$10.56 $\times 10^6$
	Cost of SNG Produced	$ 4.24 / 10^3 SCF

TABLE XL

ESTIMATED WORK FORCE REQUIREMENTS FOR AN SNG PRODUCTION FACILITY FOR FORT BENNING

Skill Category	Number of People
Supervision and Clerical:	
Manager	1
Operating foremen (1 per work turn)	4
Maintenance foreman	1
Office staff (1 per work turn + 1 five days per week)	5
Operating Personnel:	
Pretreatment operators (5 per work turn)	20
Pretreatment helpers (5 per work turn)	20
Digester and vacuum-filter operators (5 per work turn)	20
Gas purification train operators (1 per work turn)	4
Gas purification train helpers (1 per work turn)	4
Truck terminal helpers (5 days per week)	3
Laboratory technicians (5 days per week)	2
Maintenance Personnel:	
Journeymen (1 per work turn + 3 five days per week)	8
Helpers (1 per work turn + 3 five days per week)	8
Boiler and Turbo-generator Personnel:	
Operator (1 per work turn)	4
Helper (1 per work turn)	4
Total Work Force	108

TABLE XLI

INFLUENTIAL FACTORS ON CAPITAL AND OPERATING COSTS OF AN SNG PRODUCTION FACILITY AT FORT BENNING

Parameter	State-of-the-art Value for Parameter	Realistically Possible Value For Parameter	Cost Influenced	Magnitude of Cost Influence	Capital	SNG $\$/10^6$ Btu
1. Energy for grinding	17 Hp.-days per dry ton	14	Electricity	$\$-275\times10^3$	$\$31.2\times10^6$	$ 4.13
			Replacement Costs	-3×10^3		
2. Retention time in digesters	15 days	12	Digester Cost	-2130×10^3	29.1×10^6	4.17
			Electricity	-35×10^3		
			Replacement Supplies	-43×10^3		
			Replacement Costs	-107×10^3		
3. Solids content of feed slurry	12%	15%	Digester Cost	-2130×10^3	28.8×10^6	4.14
			Heat Exchanger Cost	-70×10^3		
			Steeping & Mixing Tanks	-159×10^3		
			Boiler Fuel	-70×10^3		
			Electricity	-35×10^3		
			Maintenance Supplies	-47×10^3		
			Replacement Costs	-118×10^3		
4. Solubilization of woody material	1%	10%	Digester Cost	-959×10^3	30.2×10^6	4.20
			Heat Exchanger Cost	-32×10^3		
			Steeping & Mixing Tanks	-72×10^3		
			Boiler Fuel	-32×10^3		
			Electricity	-17×10^3		
			Maintenance Supplies	-21×10^3		
			Replacement Costs	-53×10^3		
5. Cost of plant material	$11.26 per dry ton	$10.40	Plant Material	-241×10^3	31.2×10^6	4.15
			Replacement Costs	-2×10^3		
6. Split between methane and carbon dioxide in digester gas.	50% methane	60%	The amount of gas needed at Fort Benning could be produced with a four-train plant processing less material, which changes completely the basis for the calculations.		25.3×10^6	3.68

TABLE XLI (continued)

INFLUENTIAL FACTORS ON CAPITAL AND OPERATING COSTS OF AN SNG PRODUCTION FACILITY AT FORT BENNING

Parameter	State-of-the-art Value for Parameter	Realistically Possible Value for Parameter	Cost Influenced	Magnitude of Cost Influence	Capital	SNG $\$/10^6$ Btu
7. Combined benefits of best values of all of the above (effect of first five factors on cost basis of *sixth factor*)			Digester Cost	-3588×10^3	$\$21.5 \times 10^6$	3.51
			Heat Exchanger Cost	-77×10^3		
			Steeping & Mixing Tanks	-178×10^3		
			Plant Material	-209×10^3		
			Boiler Fuel	-89×10^3		
			Electricity	-54×10^3		
			Maintenance Supplies	-76×10^3		
			Replacement Costs	-4×10^3		

TABLE XLII

TOTAL ESTIMATED COSTS OF ENERGY PLANTATION SYSTEMS FOR FORT BENNING

	Central Heating System		SNG System
	With Condensate Return	Without Condensate Return	
Operating Factors:			
Plant Material-dry tons per yr.	220,000	270,000	280,000
Plantation area at 8.8 dry tons per acre-year	25,000	30,700	31,800
Capital Costs:			
Plantation at 8.8 dry tons per acre-year	$\$6.3x10^6$	$\$7.5x10^6$	$\$8.4x10^6$
Central heating system	$42.8x10^6$	$41.5x10^6$	-
SNG production system	-	-	$31.2x10^6$
Totals	$\$49.1x10^6$	$\$49.0x10^6$	$\$39.6x10^6$
Capital cost per 10^6 Btu at present fuel-consumption rate:	$19.50	$19.50	$15.80
Operating Costs:			
Central heating system	$\$ 7.4x10^6$	$\$ 8.1x10^6$	-
SNG production system	-	-	$\$10.6x10^6$
Operating Cost per 10^6 Btu at present fuel-consumption rate:	$2.92	$3.22	
Operating cost per 1000 SCF of SNG produced			$4.24

XII. ENERGY PLANTATION SYSTEMS FOR ARMY BASES GENERALLY

XII.A. Energy Plantation Solid-Fuel Systems. On the basis of the detailed estimates for Forts Leonard Wood and Benning, the capital costs at a particular base of central heating systems with and without condensate recovery appear to be about the same when the systems are designed for solid fuel from Energy Plantations (see Tables XXVIII and XLII). The capital cost for a system without condensate recovery is lower than the cost for a system with condensate recovery, but more fuel is required for the former type of system, necessitating an increased capital cost for the plantation producing the fuel. The overall capital costs for a particular base for the two types of central heating systems fired with solid fuel thus appear to be about the same.

However, at both Fort Benning and Fort Leonard Wood, the estimated annual operating cost of an Energy Plantation central heating system with condensate reuse appears to be about ten percent less than for a system in which condensate is not reused. This difference in cost is almost entirely attributable to the difference in the amount of fuel required by the two systems. Moreover, because a system without condensate recovery requires more solid fuel, it will also require a larger plantation than would be needed if condensate is recycled.

These comparisons of capital, of operating costs, and of land requirements lead to the conclusion that when a central heating system using solid fuel from an Energy Plantation is considered for an Army base, a system which recovers and recycles condensate will usually be preferred over one which does not. The estimates summarized in Tables XXVIII and XLII also suggest that the capital cost of such a system is about nineteen or twenty dollars per million Btu per year of fuel fired for systems having fuel-firing capacities in the range of those at the two forts. This estimated capital cost is subject to some influence from the capacity of the installation, but this influence is limited primarily to the cost of the boilers and precipitator installations, which account for only about half the total capital cost of the entire plantation system.

The operating cost of an Energy Plantation central heating system with condensate return is probably around three dollars per million Btu of solid fuel fired in the system (see Tables XXVIII and XLII). This cost is relatively insensitive to the scale of the system.

The overall operating cost per million Btu of an Energy Plantation central heating system cannot be compared directly with the present cost of gas or fuel oils used at Army bases, because the plantation system cost necessarily not only includes the cost of producing the fuel in the plantation and delivering it to its point of use (about one dollar per million Btu), but also the costs of burning it, distributing the steam generated to the point where heat is needed, maintaining the heating plant and steam-distribution system and replacing equipment as it wears out. The equivalent system cost per million Btu based on clean-burning oil at current prices (two dollars and probably somewhat more per million Btu) fired in the heat-delivery systems currently in use at Army bases, however, cannot be very different from the estimated operating cost for solid-fueled Energy Plantation central heating systems. Moreover, the cost of fuel oil is likely to rise in the future relative to the general price level, whereas the cost of operating a central heating system based on solid fuel grown in an Energy Plantation is likely to remain relatively steady, or even to decline, relative to prices generally in the next decade or two for the "learning-curve" reasons discussed in section X.M.

The comparison of the operating cost per million Btu fired in a central heating system using solid fuel from an Energy Plantation, with the corresponding cost of gas-fired heat-delivery systems used these days at Army bases is less favorable for the Energy Plantation system than it is when oil is the competing fuel. However, comparison with gas-fired systems may be academic because of the increasing stringency in the supply of natural gas. Certainly, if natural gas is substantially replaced by SNG produced from coal at the cost generally quoted recently by gas-from-coal proponents (three to four dollars per million Btu), the operating cost of central heating systems using solid fuel from Energy Plantations will be competitive with SNG from coal at Army bases.

XII.B. Energy Plantation SNG Systems. Comparison of the costs of SNG systems based on Energy Plantations with the costs of the present means for delivering heat at Army bases is less clear-cut than is the comparison involving solid fuels from plantations. The reason is the absence of process design data for SNG systems, which makes capital and operating cost estimates for them far less precise than for systems based on solid fuels from Energy Plantations.

Interpretation of the limited state-of-the-art information available on making SNG from plant material suggests that the capital cost of a plantation system which produces SNG is about sixteen dollars per million Btu per year as SNG (see Tables XXVIII and XLII). This estimated capital cost is lower than the corresponding estimated cost for central heating systems based on solid fuel from plantations.

The capital cost for SNG systems is only moderately affected by the scale of SNG production at a given facility, because only in the cost of the gas purification train and boiler and turbo-electric plant does the scale have much effect on capital cost. The capital cost of these two elements is about twenty percent of the total capital cost of the system (plantation and SNG plant).

The estimated operating cost of an SNG Energy Plantation system in which the SNG plant design is based on the state-of-the-art information is about four dollars per thousand standard cubic feet (one million Btu) of SNG produced (see tables XXVIII and XLII). This operating cost estimate is not notably sensitive to the scale of SNG production, nor is it likely to increase very much in the next decade or two relative to the general price level, for the same reason discussed for central heating systems based on solid fuels grown in plantations. However, this estimated operating cost is about a third higher than the estimated cost of operating central heating systems with solid fuel from Energy Plantations.

If the state-of-the-art information on producing SNG from plant material is reliable for process design purposes, then an SNG plantation system has a higher operating cost than a solid-fueled central heating system, although the capital cost of an SNG plantation system is about twenty percent less than the capital cost of a solid-fueled system. From these estimates, it would be concluded that solid-fueled central heating systems are likely to be preferred for Army bases when Energy Plantations are being considered.

This situation, however, could be entirely different if the state-of-the-art is an unreliable guide for designing SNG production facilities. If the design parameter values approximate those shown in the seventh entry in Table XLI, the capital cost of SNG plantation systems would be only about twelve dollars per thousand standard cubic feet (one million Btu) of annual SNG production capacity, and the operating cost would be a little more than three dollars per thousand cubic feet of SNG produced (see Table II). Under these circumstances, SNG plantations would probably be the cheapest way for supplying the fuel requirements for the fixed facilities at Army bases from Energy Plantations.

Unfortunately, until more precise design data are available for producing SNG from the harvest of Energy Plantations, the practical feasibility of so doing cannot be determined, and the uncertainty associated with the technology and the resulting uncertainty in estimated costs cannot be qualified.

XII.C. Other Considerations. This study is a first look at the use of Energy Plantations for Army installations, and as such, there is uncertainty associated with the cost estimates. There is, however, more uncertainty involved in the estimated costs for the central heating system and the SNG production plant than in the costs for the plantation producing the plant material. In the latter case, the costs are generally based on actual experience and operating data. However, on the basis of the cost estimates developed in this study, certain general conclusions can be drawn. It is concluded that the operating cost of meeting the heat requirements for fixed facilities at Army bases from central heating systems fired with solid fuel grown in Energy Plantations may already be, or soon will be, competitive with the corresponding cost of the oil-fueled systems now in use at the bases. It is also considered very likely that the operating cost of these Energy Plantation systems will be competitive with the gas-fueled systems at Army bases in the next decade or so if by that time a substantial part of the gas is SNG produced from coal. Finally, it is concluded that SNG produced from plant material grown in plantations may be cheaper and more convenient to use than solid fuel from the plantations. However, to achieve these operating-cost advantages by producing and using fuel grown on Energy Plantations, the capital cost may be between twelve and about seventeen dollars per million

Btu of fuel production capacity per year.

Fortunately, this investment would lead to several important benefits for the Army and the national interest. Among them are:

- Army bases in those localities where climate and terrain are suitable for Energy Plantations would have a firm, domestically controlled source of fuel grown on land which may have little or no use at present;
- establishment of Energy Plantations at Army bases would relieve gas and fuel for use elsewhere in the nation;
- fuels derived from Energy Plantations would avoid the problems with sulphur oxides and other air pollution which tend to be associated with fossil-fuels combustion;
- development and demonstration by the Army of systems required for supplying troop training centers with fuel from Energy Plantations would be in the national interest because the technology involved would have wide application in the nation generally; and
- Army leadership in developing solutions to the national problem with energy supply for the future would be clearly demonstrated.

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