MODELLING THE EFFECTS OF ALTERNATIVES IN NATURAL ENERGY SYSTEMS
IN SMALL AGRICULTURALLY ORIENTED COMMUNITIES

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This thesis discusses the current status of "integrated systems" and the need for a better understanding of the behavior of such systems. One possible method of increasing that understanding, the development of a systems dynamics computer model, is described in detail. The model is structured to enable the exploration of the effects of a range of combinations of alternative energy technologies in a community. For the purposes of this study, a small agriculturally oriented community was examined; major elements of the model cover agriculture, waste treatment and biogas production, solar and wind energy, building energy flow, and cash and labor interactions. The results of any given simulation with the model are in a sense an abstraction of the quality of life in the community and are presented in terms of the amount of labor and money required over a period of time to sustain the investment in capital and the ongoing operation of the basic community structure modelled. Several simulations using different distributions of investment in alternative energies are presented; interpretation of the resulting behavior and the usefulness of the model as a planning tool are discussed, as well as the limitations of the structure of the present model.

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Preface

PREFACE

The concepts of using and combining natural energy systems are not new; societies have used ambient energy resources for centuries. Wind and water mills, animal and human labor, sun and rain, and waste returned to the fields all contributed to a healthy ecological balance. The process continues in some parts of the world, sustaining China for 4000 years, but modern western technology with ever increasing separation of production from consumption has managed to break the ecological chain. Western civilization uses energy to plug the break in the ecological chain, but it is a solution that cannot last.

Total energy consumption in the United States was 1.71×10^{16} kcal in 1971 (1); of this total, domestic space and water heating was 15.5 percent, while other domestic energy use, including food related activities, accounted for another 4.5 percent (2). Outside the home, the modern agriculture-food processing system used 11 percent of the national total, including 10 percent of all petroleum in powering machinery and manufacturing fertilizers (2, 3). The use of this energy has frequently created vicious cycles which require greater and greater inputs of energy. The rich soils of the midwest have in some places been depleted to a level as low as 60 percent of their original fertility in only 68 years (4); actual production is maintained and increased through great amounts of energy in the form of artificial fertilizers, chemicals, and fuels, until for some crops more energy is put in than is available at harvest (3,5). Habits of wastefulness and extravagance were developed as fossil fuels became cheaper and their use more convenient. The false assumption that these energy sources are unlimited lingers, but there is a growing awareness of the need to conserve them and to develop new sources of energy based on renewable resources. Fortunately, the domestic and agricultural sectors of the national economy, which account for fully 31 percent of total energy use, are probably most adaptable to the use of natural energy sources, and there is the further advantage that the energy is generally available where the demand exists.

Natural sources of energy, particularly solar and wind, have been vigorously studied for at least the past 100 years, but their implementation on a large scale, except in some particularly favorable locations, has languished in the face of the availability of relatively inexpensive natural gas and petroleum. In the past few years, however, natural forces have again begun to receive deserved attention as important sources of renewable energy for our present and future needs, and *integrated systems* and *autonomy* have become fashionable bywords in certain segments of the population of the developed countries. There are at least two major reasons for the resurgence of interest in natural energy systems, the primary being a reaction to real or perceived shortages of energy and materials, as well as increasing prices. Underlying this reaction is the recognition that the world has only a finite amount of non-renewable resources which must be conserved for future generations.

Beyond these reactions lies a wide range of technical actions. On the one hand, complete isolation and independence may be sought; some "back to the basics" philosophers live in essentially primitive or middle ages conditions. The other extreme is represented by those who would achieve independence at any cost, but only if all the comforts and amenities of modern society are maintained, the so-called "technological fix." Another, healthier reaction recognizes the fact that we are all interdependent to some degree and seeks to discover the optimum amount of autonomy, which may well vary from one context to another.

No matter what form the reaction to the energy crisis takes, natural forces cannot simply be substituted for fossil fuels. While they are renewable (where, for practical purposes, the fossil fuels are not) their generally low density and consequent cost of transforming them into usable forms means that we must seek a reappraisal of our energy requirements, as it is unlikely that gluttonous energy demands can be satisfied with natural forces. Clearly, the first step in the utilization of natural energy sources must be to be conservative in the use of energy in any form (6).

NOTES TO PREFACE

(For complete citations, please refer to the Bibliography)

1 Schipper and Lichtenberg, p 1002. 1.71×10^{16} kcal is equivalent to 1.99×10^{13} kilowatt hours. Throughout this paper I have used different units of energy for different uses, in keeping with common associations. Thus heating is discussed in terms of Btus, electricity in kilowatts, food in terms of kilocalories (= food calories), and fuel use in terms of kilocalories. This may be confusing at times, but everything is reduced to dollars in the end.

2 Steinhart and Steinhart.

3 Heichel.

4 Meadows, p 263.

5 Pimental *et al*.

6 Tom Bender offers a very compelling philosophical and factual argument for energy conservation in his paper "Living Lightly."

1
Autonomy and Integrated Systems

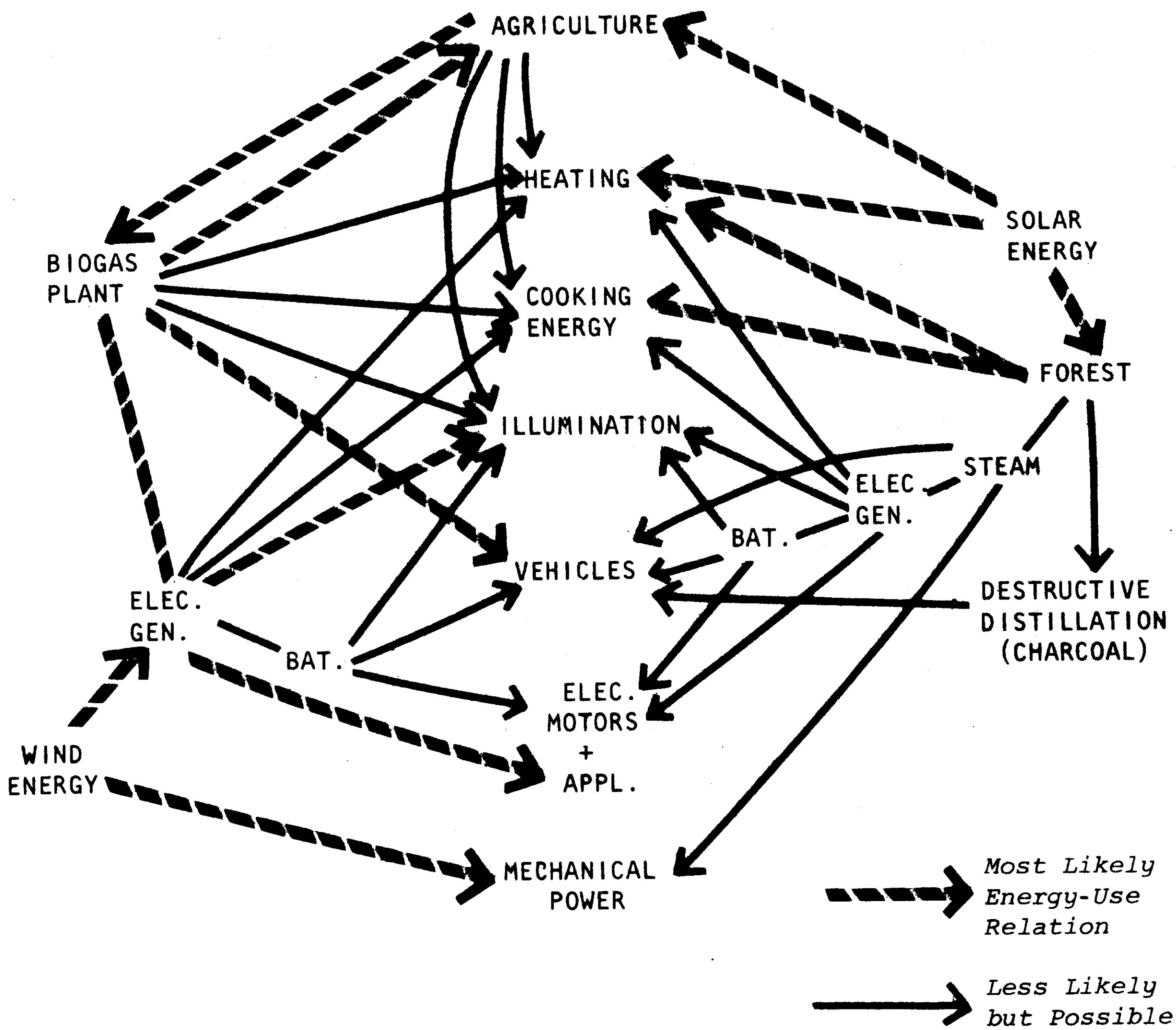
DEFINITIONS AND OBJECTIVES

Autonomy, in its simplest defintion, expresses the idea of self-sufficiency, self-reliance, and independence from outside sources of supply. Implicit in many applications of the term, but not necessary to it, is the concept of recycling energy and materials through the system. The methods of achieving autonomy have been classified by one writer as 1) *Making Do*, or reducing standards of consumption, comfort, etc.; 2) *Clever Ideas*, making better use of presently available resources; and 3) *Alternative Resources*, or utilizing, for instance, solar collectors and wind generators. This classification is proposed in Peter Harper's remarkably comprehensive chapter on autonomy in the book *Radical Technology* (1); the work thoroughly analyzes a wide range of autonomy's economic, political, and social implications. Harper presents and analyzes many proposals for autonomous homes, and while he does not propose a specific system himself, he does point out the limitations of autonomy, particularly with regard to single dwelling units. He indicates that the direction to look is towards the community and collective levels of autonomy. Since such a thorough exposition of autonomy is beyond the scope of this thesis, I will refer the reader to that chapter for details and simply suggest in this and the next section some of the major issues arising from consideration of autonomy and integrated systems.

As attempts are made to achieve autonomy through the use of renewable resources, the idea of combining different sources of energy naturally follows as a response to the intermittent and low density characteristics of many ambient energy sources, particularly the sun and wind. Some means must be sought to match and level supply and demand, to cascade or reuse in other forms both material resources and energy in the system, and to add stability to it. The phrase *integrated system* is generally used to refer to a system which accomplishes these objectives.

In integrated systems, available energies might be utilized in forms most appropriate to the purpose at hand; solar heat, a low grade energy, would be suitable for space heating or agricultural drying, for instance, while mechanical power could be supplied by the wind, which could also be used to produce a higher grade of energy in the form of electricity. Storage requirements for higher grades of energy could be minimized by using energy as much as is practicable at the time it is available. In order to achieve greater overall efficiency, material resources and energy in an integrated system could have both primary uses (such as water used for human consumption and washing and biogas used to generate electricity) and secondary uses (as when used water is again used, say for irrigation, and when waste heat from a generator is used to heat a biogas plant). With a number of different sources for energy potentially available, the stability of a system is enhanced; it would likely be economically prohibitive to attempt to achieve the same degree of stability with a single source of alternative energy. The probability of being able to meet a demand for energy increases as the number of sources available increases, even with only moderate sizes of individual subsystems and storage capacities. Stability can be further enhanced by transforming ambient solar energy into other forms which can be stored easily and used whenever needed; examples of this transformation include food energy, wood energy, and biogas generated from agricultural wastes. Some information regarding these concepts can be found in Golding and Thacker (2), Weintraub (3), and *Energy Primer* (4). The latter two are strongly based on the Golding paper, but the *Energy Primer* also discusses the efficiencies of conversion from one form of energy to another.

The terms *autonomy* and *integrated systems* are closely related and are at times used indistinguishably. Often *autonomy* is used with reference to units at the individual dwelling scale and *integrated systems* to community scales, but this is neither precise nor informative. Practically speaking, autonomy could exist at any scale without having an integrated system, and integrated systems could and do exist in non-autonomous contexts; here, however, integrated systems will be considered as a means to autonomy, or at least stability.



Potential Energy-Use Relationships
Fig. 1

IMPLICATIONS AND LIMITATIONS

The primary natural forces available to the autonomous integrated system are solar and wind energies; these are found, to a greater or lesser extent, nearly everywhere. Water power or tidal energy might be appropriate in specific situations. Derived from solar energy, but not always available, are the biofuels, which include food, wood, and biogas, a further derivation. These are the basic building blocks of all autonomous systems; Figures 1 and 2 and the following description give some idea of how they might be utilized to satisfy the demands of the system.

The requirements for energy as low grade heat for space heating are closely matched by solar energy in most areas; the rule of thumb for sizing solar collectors, one square foot of collector to two of floor area, testifies to this. Some auxillary or back-up heat is usually necessary (unless very large and often uneconomic solar storage is provided) - this could be wood or biogas, if used sparingly, although these are higher grades of energy. Although wind generated electricity has been suggested as both a back-up and a primary source of space heat, mostly to avoid problems of storage, it is a shame to use such high grade energy in a low grade capacity. Wind power, if the site is favorable, would be appropriate for both mechanical processes and generation of electricity. A biogas plant could be utilized both to process human and animal wastes, but also to make available in a useful form the energy in the wastes, both as biogas and as fertilizer. The gas could be used to provide motive power for machinery, to generate electricity or for cooking (although wood burning cook stoves are probably more appropriate for northern New England). The production of biogas could be greatly augmented by the inclusion of vegetable wastes in the digester; this is particularly suitable for an agricultural community. The foregoing is by no means a complete summary of the techniques available to achieve autonomy; the reader is referred to the bibliography for this.

Although it is true that autonomy can be achieved at the scale of the individual dwelling unit, autonomy at larger scales provides the opportunity to make more effective use of most alternative energy sources. It must be cautioned that the larger scale must not be created by the simple aggregation of individual autonomous units, but should take on characteristics of its own. If the starting point in the development of the autonomous integrated system is taken as the conservation of energy use, the overriding characteristic of the community would be its compactness. A report prepared for the Council on Environmental Quality (5) states that both construction and energy costs can be reduced by 40-50 percent in high density development over "low density sprawl." There is reason to believe that the cost savings would be even more significant for integrated systems, due to the lower density of the available power and the high unit costs of alternative energy hardware in small sizes. Besides savings associated with compactness, the use of such alternative energies as wind power and biogas, and possibly solar energy (through seasonal storage), would be facilitated in a larger community. In more pragmatic terms it is probably easier for a community to obtain adequate financing than it is for an individual. If economies of scale are achieved, it would result in a lower investment per person, but in any case there will be more cushioning in the case of individual insolvency.

Larger scales allow site optimization for wind power, whereas a small autonomous unit might not have much choice in the matter. More efficient processes for waste digestion are practical and can be justified by the amount of waste available, especially if the community is agriculturally oriented. Seasonal solar storage, which is uneconomical for the individual dwelling, becomes more promising when many units share the same storage, and overall collector area can be reduced as well. It would be well to note that the advantages of larger scales must be considered in the context of community density, and must be balanced against the costs of distributing the energy to the community, and further, that there is an optimum size for autonomy, given a specific set of parameters, beyond which there is a declining margin of productivity.

Purely social implications of autonomy are somewhat more complex. At a small scale, i.e., the individual dwelling unit, social cohesiveness and unity of purpose might be a prerequisite to autonomy (although the attitude of the inhabitants towards the greater society might be one of rejection), but autonomy at a larger scale would not *necessarily* require social cohesiveness. Although the type of social organization would have a definite influence on the physical form an autonomous community would take, it is probably safe to say that a given physical structure would remain adaptable to many different forms of social organization. Autonomy would benefit from social cohesiveness, however, as it facilitates physical forms which promote conservation of resources and makes possible economic provision of amenities which would not be justifiable at small scales of autonomy. Shared facilities such as recreation areas and equipment, workshops, laundries, and educational and research facilities would be reasonable to include because of their fuller utilization. It is also possible that the inhabitants of larger autonomous communities would be more likely to recognize and accept the ways in which they would still be dependent, however slightly, on the rest of society.

Awareness and acceptance of the social and physical limits to autonomy might enable more efficient autonomous communities to evolve; there may be an optimum social scale to autonomy, but it must be one which maintains the importance of the human element. In these circumstances, it is not difficult to imagine the existence of numerous materially autonomous communities or regions, freely associated with one another, sharing certain responsibilities, such as means of communication, which would be impractical for each individually.

SOURCE	DEVICE	PRACTICAL USE	IMPRACTICAL USE
SOLAR	Collector	Space heat Water heater	Heat pump
	Greenhouse	Food production	
	Dryer	Food drying	
	Concentrator	Cooking	
	Photovoltaic cell		Electricity
	Steam boiler		Electricity
WATER (where available)	Water turbine	Electricity	Air compression Electrolytic (H_2) Fuel cell
	Water wheel	Mechanical power Air compression D.C. electricity Heat pump	Flywheels A.C. electricity
	Hydraulic ram	Pumped water	
WIND	Generator	Electricity	Air compression Electrolytic cell (H_2) Fuel cells
	Windmill	Water pump Mechanical power Air compressor Heat pump	Flywheels
BIOFUELS	Photosynthesis	Food	
	Food and feed	Sustenance	
	Organic waste (methane)	Combustible fuel	Mobile engine
	Wood	Heat	Wood gas Methanol
	Biomass		Ethanol Electricity
	Compost	Heat Fertilizer	

PRACTICAL AND IMPRACTICAL CONVERSION AND STORAGE USES. (AS OF LATE 1974)

Fig. 2 Ref. (4)

CURRENT RESEARCH

Some of the proposals which have been put forth for "autonomous" dwellings attempt to integrate different service subsystems, while others concentrate all their effort on one or two specific subsystems, primarily solar heating and wind energy. This latter type might with more accuracy be termed "self heated" or "electrically self sufficient" rather than autonomous. The problem of establishing the degree of self sufficiency or autonomy really depends on whether "self sufficiency" is intended to apply only to a building structure and its machinery, or to its occupants as well. If the occupants are truly considered part of the dwelling system, the scope of autonomy *must* be enlarged to include food production and the means of making a livelihood. This may imply field crops and animal husbandry, as well as intensive greenhouse agriculture or aquaculture. While many autonomous home proposals do include some provision for greenhouses or gardens, it often appears that this is more a symbolic gesture rather than a practical step. The food production end of the autonomous spectrum does not seem to be taken as seriously as the wind and solar aspects; apparently it is acceptable to purchase chemically grown food, perhaps grown thousands of miles away, but not acceptable to purchase other forms of energy. There is a slight irony inherent in highly technological autonomy that tends to ignore the contributions which can be made by ancient traditions of agriculture - can a system really be termed autonomous if it depends so heavily on extractive technology?

Not a great deal of serious research has yet been done on completely integrated systems, but studies of partially integrated systems, or of weakly linked subsystems have been done. Most proposals have been stronger in solar or wind technology than in water, waste, or food subsystems (6,7), although there are a few exceptions to this generalization (8,9). Some proposals which at first sight appear to be fully autonomous integrated systems have serious drawbacks when analyzed a little more closely. Most of the proposals in which cooking energy is to be derived from biogas digesters, for instance, will probably not work out unless they also have animals or a great deal of vegetable waste available (10).

The individual autonomous dwelling has received the greatest amount of study so far because it conforms to certain social preconceptions and because of the small scale. It is certainly destined to be overstudied with respect to larger forms of autonomy. The amount of information available on larger scales of autonomy is rather small and much of it is speculation, rather than concrete research. Golding proposed, in the early 1950's, to combine wind, waste, and solar systems for rural energy centers in Africa (2,11). Brace Research Institute in Montreal works along these lines today, developing means to integrate alternative energy sources in communities without, however, destroying the existing cultural fabric with overwhelming western technology (12). Although the University of Cambridge Autonomous Housing Study analyzed the effects of scale on the cost of servicing by normal means (13), it is strange that none of their specific autonomous (dwelling) proposals deal with anything greater than a single family structure. Some graduates of the University program developed and attempted to carry out proposals at slightly larger scales, although still little more than at the extended family scale (14). In the United States, the developers of Grassy Brook Village, a condominium in Vermont for ten families, at first intended to utilize solar and wind energy and to generate biogas, but have since retrenched somewhat from these plans and it is not certain that it will be constructed as envisioned (15); this is still not a very large community, however. Harper and Merrill (1,4) speculate about larger scales of autonomy but present no hard data or calculations.

There is little evidence either that detailed studies have been carried out on the overall behavior of proposed integrated systems; although numerous simulation studies of certain subsystems, notably solar collector-storage interrelationships, have been performed (16), they have not yet been done in the context of integrated systems. There is a definite lack of understanding, therefore, of what actually happens in most integrated systems, even though most designers have some idea of what they *hope* their systems will do. If a convenient method of analyzing integrated systems were available, many current proposals would probably be found to be unrealistic at the least, and at best uneconomic. As more complex systems are developed and more interconnections are made between subsystems, the need increases for dynamic analysis in order to evaluate the behavior of the system. Feedback loop systems are inherently dynamic and as such are not easily analyzed by traditional methods.

NOTES ON AUTONOMY AND INTEGRATED SYSTEMS

(For complete citations, please refer to the Bibliography)

1 Harper, "Autonomy."

2 Golding and Thacker.

3 Weintraub.

4 Energy Primer, p 178.

5 Real Estate Research Corporation. This report indicates that a high density community results in 44% lower investment cost, 55% less roads and utilities, 45% less air pollution, and 44% less energy consumption compared to low density sprawl.

6 Pike.

7 See examples in Harper; *Energy Primer,* p 181.

8 "An Ark for Prince Edward Island," NAI; *Energy Primer,* p 181.

9 Smith. Although some of the University of Cambridge designs have gardens most do not.

10 It is doubtful whether Longland, Pike, or Crouch's designs which intend to use biogas as a major fuel will have nearly enough. (See summaries in Harper, pp 149-159.)

11 Golding, "The Combination . . ."

12 Lawand *et al.*

13 Thring, "Threshold Analysis of Services."

14 See, for example, the BRAD Eithin-y-Gaer house and The Girardet Radial House, in Harper, pp 162-3.

15 Grassy Brook Village Information Sheets.

16 Among those involved with solar simulation studies are the National Bureau of Standards, the University of Cambridge Autonomous Housing Study, Professors Pratt and Thornton of The Electrical Engineering Department at MIT, Professor Johnson of the Architectural Department at MIT, and D. Balcomb and others at the Los Alamos Research Laboratories.

2
Modelling Integrated Systems

OBJECTIVES AND BENEFITS

If it is attempted to bring into realization some of the integrated systems which currently exist only as proposals, it is likely that they will fail to achieve their goal. This is ~~due~~ in part because the designer does not ~~to the lack of~~ understand~~ing of~~ the principles of individual components, as for instance, ~~the~~ consistent expectation that biogas digesters will be able to supply a large proportion of a dwelling's fuel requirement with only a minimal input, but also because the designer has no realistic way to evaluate the trade-offs between the different subsystems. There are at least two consequences of failure: 1) the designer will have spent a good deal of effort and time on developing an impractical solution, and 2) the builder (whether or not the same as the designer) will suffer the loss of the time, money, or confidence (or all three) involved in the undertaking. At the present time there is no practical alternative to building on faith; the best the designer can do is to thoroughly evaluate the separate components. An approach which models the behavior of complete systems would be a distinct benefit.

Although something can almost always be learned from failure, it would be better if designers of integrated systems could avoid faulty approaches and blind alleys. The high costs of integrated systems make it unlikely that many failures could be sustained in any case. A good model of integrated systems could lead to improved planning capabilities and decisions could be made with a reasonable understanding of their probable consequences. Understanding the implications of any given community structure would also greatly benefit the designers of integrated systems. If a community wished to establish itself as an autonomous integrated system, it would in real life have an only finite amount of resources available to it in the form of labor and money. Since the investment necessary to establish and maintain a self sustaining community could be considerable, the community would desire to allocate its resources to the various components of the system in such a manner as to optimize its particular objectives. While research has been done on the optimization of some alternative energy subsystems, and on optimization of investment in energy systems (1), there is still a need for a method to permit the optimization of combined systems.

Ideal Integrated System Model Characteristics

The ideal model of autonomous integrated living systems would allow all possible variations of autonomy, both social and technical, to be evaluated. Differences in climate, building morphology, scale and density, subsystem hardware, capitalization and consumption and use patterns could be studied as well as different degrees of autonomy and system integration. The ideal model would allow the system to be studied for either its technical or social implications. The model must also be capable of simulating behavior of the system over extended periods of time, with erratic as well as steady state input. A static model of an integrated system would not be very helpful, since what is really desired is knowledge of system behavior over a period of time. Construction of such a model would necessitate considerable research just identifying and evaluating all the possible parameters, and establishing variations in them and their relationships to one another, besides the work of creating the model structure and adjusting it to accept the wide range of input. At the present time the data base necessary for construction of the ideal model simply does not exist; while it would be a desirable step in the study of integrated systems to create this data base, it is more than can be reasonably attempted within the context of this paper.

Community Integrated System Model

So far this paper has outlined the concepts of autonomy and integrated systems and indicated the status and limitations of present knowledge of these concepts. The balance of the paper describes the development and preliminary dynamic analysis of a specific model of an integrated system within the context of the ideal model described above. Because of the scarcity of existing models and the fact that integrated systems study is in its infancy, even a limited specific model could be of value to designers, particularly in the method of construction. The problem inherent in modeling integrated systems would be outlined for others involved in similar work, even if the specific model has a limited range of application.

The modeling technique chosen was that of systems dynamics, in particular the DYNAMO computer language, developed by the industrial dynamics group at the MIT Sloan School of Management. Since this language was designed specifically for simulating dynamic feedback models of continuous systems, and was "designed for the person who is problem-oriented rather than computer-oriented (2)," it seemed appropriate to the modeling of a complexly integrated system which, presumably, would be required to operate continuously in support of its inhabitants, and which might well be designed by persons not particularly familiar with basic computer languages. A summary of DYNAMO equation types is given in the appendix, but the reader is referred to the *DYNAMO Users Manual* (2) for a complete description of the DYNAMO language and how to use it.

The objective of the community integrated system model is to permit the analysis of the behavior of the system at the scale of a small community in terms of readily understandable human requirements. System parameters include the various energy subsystems and the food, waste handling, and building subsystem. Subsystem inputs can be varied within reason in different model simulations. Determination of what is meant by system "behavior" is crucial to the formulation of the model. Since the study deals with a *living* system it seems natural to attempt to define performance in terms of human living conditions. Putting the definition in these terms requires the consideration of the relative importance of nutrition, leisure, work, shelter, safety, comfort, and social interaction, to name only a few possible parameters of well being. The community model is abstracted and simplified to give output from which quality of life might be deduced; outputs are summarized in Figure 3.

1 Hours of labor required
   a In agricultural-food sector,
   b In labor for cash;
2 Community expenses
   a Capital and fixed operating costs,
   b Auxiliary energy, materials, and food necessary;
3 Community income
   a Sales of agricultural products,
   b Cash from labor;
4 Food consumed.

Outputs of Community Integrated Systems Model
Fig. 3

These outputs can be used to determine the amount of time available for leisure or recreation, money available for amenities, as well as the standard of diet possible. The suitability of any given system for a particular client can be evaluated through comparison of the output with the desires of the client; different client value systems will result in different reactions to the same output. While it would be possible to obtain output in the form of technical summaries of system behavior, for instance the number of kilowatt hours generated, the number of BTUs collected, or the amount of fertilizer produced, this kind of data does not readily lend itself to a direct human interpretation.

The major part of the work involved translation of the social and technical parameters of the system into a form acceptable to the modeling techniques. Prior to (and sometimes concurrent with) this the subsystem possibilities and potential interrelationships were studied and quantified. The equations for the various subsystems were created and the subsystems themselves subjected to dynamic analysis. Once a subsystem model subsector exhibited satisfactory behavior it was added to the total system. The model was then tested with a variety of parameters and resulting behavior was compared to expected results. This process of testing and fine tuning the model is discussed in Chapter Four.

Validation

Validation of an integrated systems model is limited by the absence of any comparable real life systems; thus no direct comparisons can be made on the basis of complete systems. Despite this limitation there are a number of observations or tests which can be made and which may give confidence in the model. Jay Forrester, one of the founders of the Industrial dynamics group at MIT, has emphasized that usefulness of a model, in terms of the purpose for which it was designed, is more important than a "proof" of validation (3).

In order to get an idea of the usefulness of a model, the alternatives must first be considered. There are no statistical data yet available on integrated systems, inasmuch as none have been built and fully evaluated. The closest approach to date has been in the building and testing of solar collectors and storage systems. Although these are often major components of integrated systems, they do not exhibit the high degree of complexity and feedback inherent in the latter. Even proposals for integrated systems have only been studied on a component by component basis (4). Testing of individual components of integrated systems in isolation has been done to varying degrees of accuracy, but there are inconsistencies in testing procedures, reporting, and knowledge of most alternative energy systems, including solar, wind, and methane (5). If this model is perceived as a first attempt which can be made more useful as it is improved through experience, then it can be considered useful in the present. A discussion of specific concepts of validity as expounded by Forrester and as applied to the community integrated systems model will be found in Chapter Five.

NOTES ON MODELLING INTEGRATED SYSTEMS

(For complete citations, please refer to Bibliography)

1 This has mainly been limited to studies of optimal insulation and the solar collector-storage relationship.

2 *DYNAMO USER'S MANUAL*

3 Forrester, *Industrial Dynamics*, and public lectures.

4 Pike.

5 As examples, consider the multitude of ways that manufacturers determine the efficiency of solar collectors, and the ratings of wind generators which are stated for different wind speeds by different manufacturers.

3
Community Integrated Systems Model

COMMUNITY DESCRIPTION

The hypothetical community chosen for detailed development and analysis in the integrated systems model is an intentional, reasonably socially cohesive and physically compact, moderate sized, and agriculturally oriented community located in northern New England. Although the model may be adaptable to other types and sizes of communities in other locations, this community type has been chosen to illustrate the effects of integrated systems with a strong agricultural component. The specific size of about 100 persons was chosen because this scale has not been studied in the context of an integrated system and because a community this size could be expected to exhibit different behavior than a simple accretion of individual autonomous units. A moderate sized community should also be able to take advantage of economies of scale in subsystem hardware and, because of its greater resources, be able to make the best use of a given site. At the other extreme of scale, towns or cities of thousands of people generate serious problems of employment, transportation, and public services, which might obscure the basic interrelationships of an integrated systems model, particularly a first attempt.

The location and agricultural orientation were chosen for several reasons, not the least of which is a personal interest in organic farming in Maine. Aside from this predilection, it has long been apparent that New England suffers from the dual disadvantages of being literally at the end of the pipeline and transportation network, and being almost entirely dependent on the rest of the country for both energy and food. On top of these factors the region has a rather severe climate, which increases energy requirements relative to other regions in the country. The proposed community represents an approach to regional self sufficiency in food and energy production. It is an encouraging sign that several states in the region have taken steps to preserve their base of farmland (1).

The present dissociation of consumption from production requires the input of additional energy in transportation and processing, and discourages the reuse or recycling of "wastes." This is particularly true for the modern agricultural system, where grain is grown in one location, the animals which eat it in another, and the people who eat the animals in cities elsewhere. Wastes from the feedlots and cities are either stockpiled or flushed away to the sea; meanwhile, the grain grower must purchase artificial fertilizers to maintain production. An agriculturally based community which recycles its waste from each stage of food production and handling could closely approximate a natural ecological system, in which production and consumption are in balance and are interrelated. It should be noted, however, that any sales of produce from the community represent losses to it and must be compensated for.

A basic tenet of this community is the fact that the inhabitants have made a conscious decision to live in it based on a desire to live in harmony with their environment and to live close to the source of their life support. The implications of this are reflected in the way the model is formulated. Some of the implications are that the residents are more likely to accept the vagaries of sun and wind, and that they are willing to put a high priority on growing their own food and providing their own necessities. It is possible that work of this sort would be preferred to working for wages elsewhere, even if the latter was more remunerative on an hourly basis. What this means in terms of autonomy and the model is that the residents are willing to accept a little lower standard in order to achieve autonomy. Thus model parameters for consumption and energy use are adjusted to reflect the conservative tendency of the community (2).

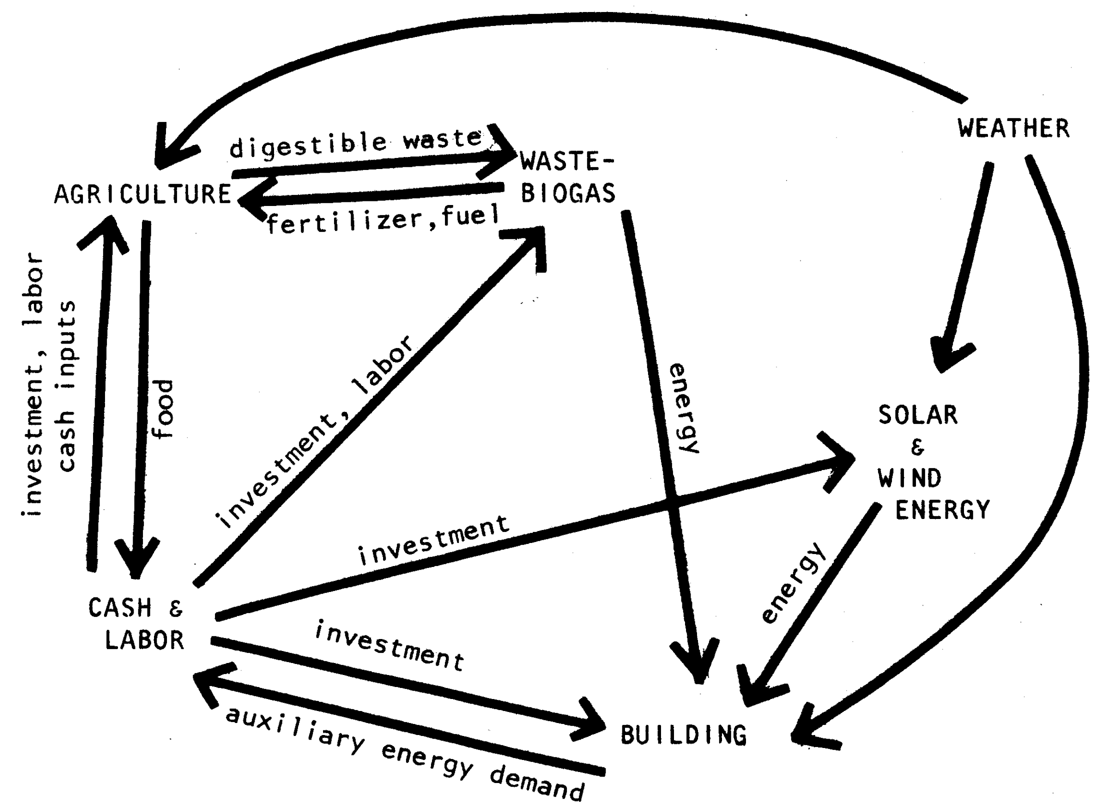
MODEL DESCRIPTION

For ease of understanding, the model is divided into several major sectors, each representing a different aspect of the integrated system under investigation. The six sectors cover agriculture and food availability, waste treatement and biogas production, solar and wind energy, building energy flows, weather data, and cash and labor interactions. The primary features of these sectors and their interrelationships are summarized in Figures 4 and 5, and are examined in detail in the following section.

SECTOR	INPUTS	OUTPUTS	COMPONENTS
AGRICULTURE	labor fertilizer other	animal waste crop waste food wood	land area greenhouses equipment
WASTE-BIOGAS	animal waste crop waste labor	biogas fertilizer	digester gas holder
SOLAR AND WIND	weather	heat electricity	solar collectors solar storage wind generator
BUILDING	heat solar gains temperature electricity cooking fuel	net energy requirements	building size window area insulation
WEATHER	--	solar radiation wind speed temperature	--
CASH AND LABOR	food sales capital investment number of people auxiliary energy requirements	money spent time worked labor available	--

Summary of Model Sectors: Principal Features
Fig. 4

It can be seen from these figures that the agricultural, waste-biogas, and cash-labor sectors are more closely interrelated than the other sectors, since they have so many complementary outputs and input requirements. These sectors also exhibit the greatest amount of internal feedback. The cash and labor sector is directly linked to all the other sectors, except for the weather sector, which simply introduces exogenous data to the system. The solar-wind and building energy flow sectors are both rather simply related to each other and to the cash-labor sector.



Primary Interrelationships of Integrated System Model Sectors
Fig. 5

NOTES ON THE COMMUNITY INTEGRATED SYSTEM MODEL

1 Maine, Vermont, and Massachusetts have passed laws designed to protect farmland and open space. If land protected under these laws is used for another purpose, there are provisions for penalties and recapture of some of the taxes which would have been paid had the property been taxed for that use all along. Maine and Vermont are also actively encouraging agriculture.

2 A complete listing of model parameters can be found in the Appendix.

a

Solar and Wind Energy Sector

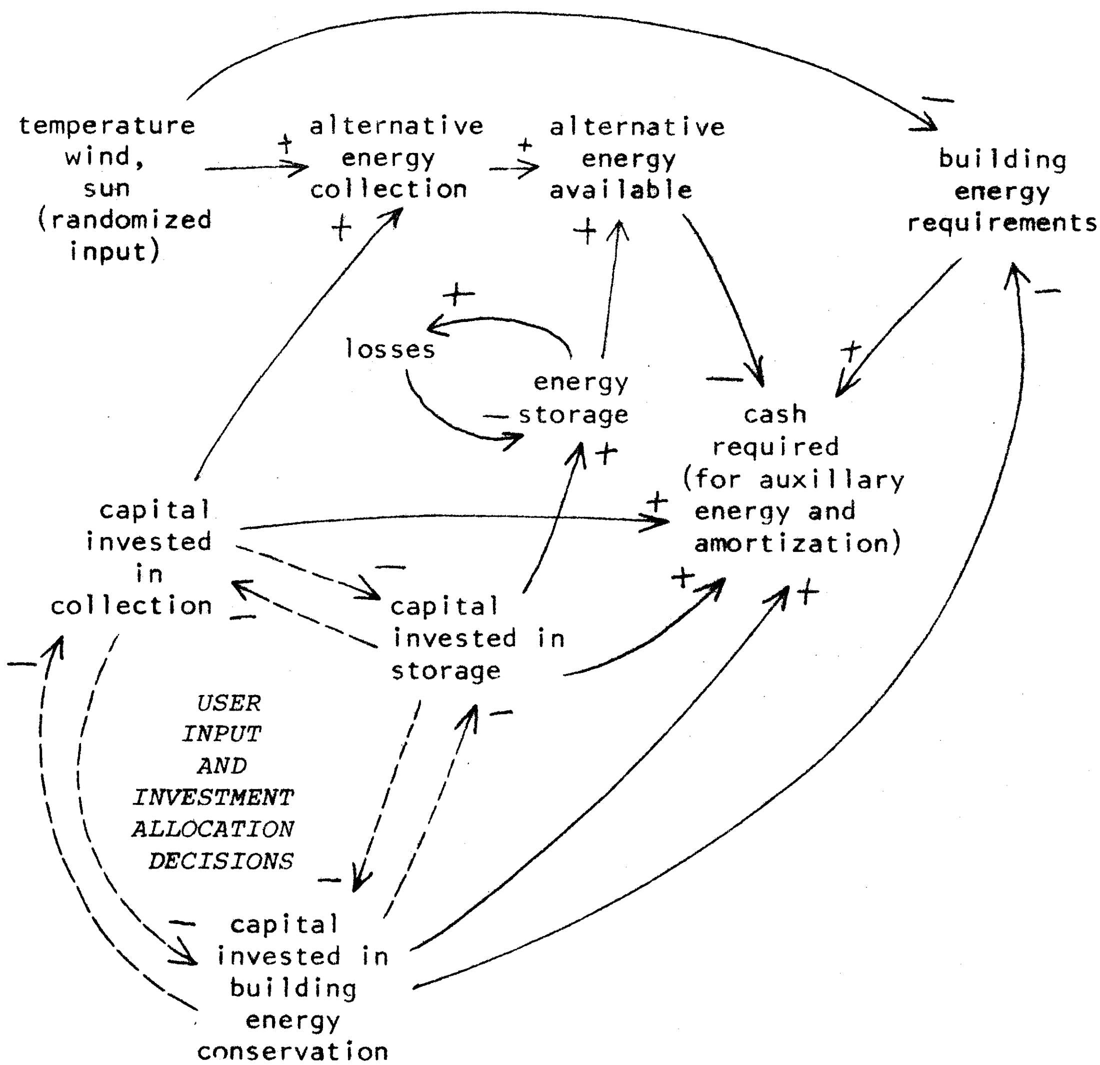
SOLAR AND WIND ENERGY

Solar and wind energies are combined in one sector since they are both links between random weather input and the energy requirements for the rest of the system. There is limited feedback within these sectors and their relationship to the rest of the model is one of capital cost and energy production; the greater the capital investment in the sector, the greater the amount of energy which can be made available, but also the greater the amortization necessary. However, a greater amount of energy captured means lower auxillary energy costs. A simplified causal loop diagram of this sector is illustrated in Fig. 6 while the complete flow diagram is shown in Fig. 7.

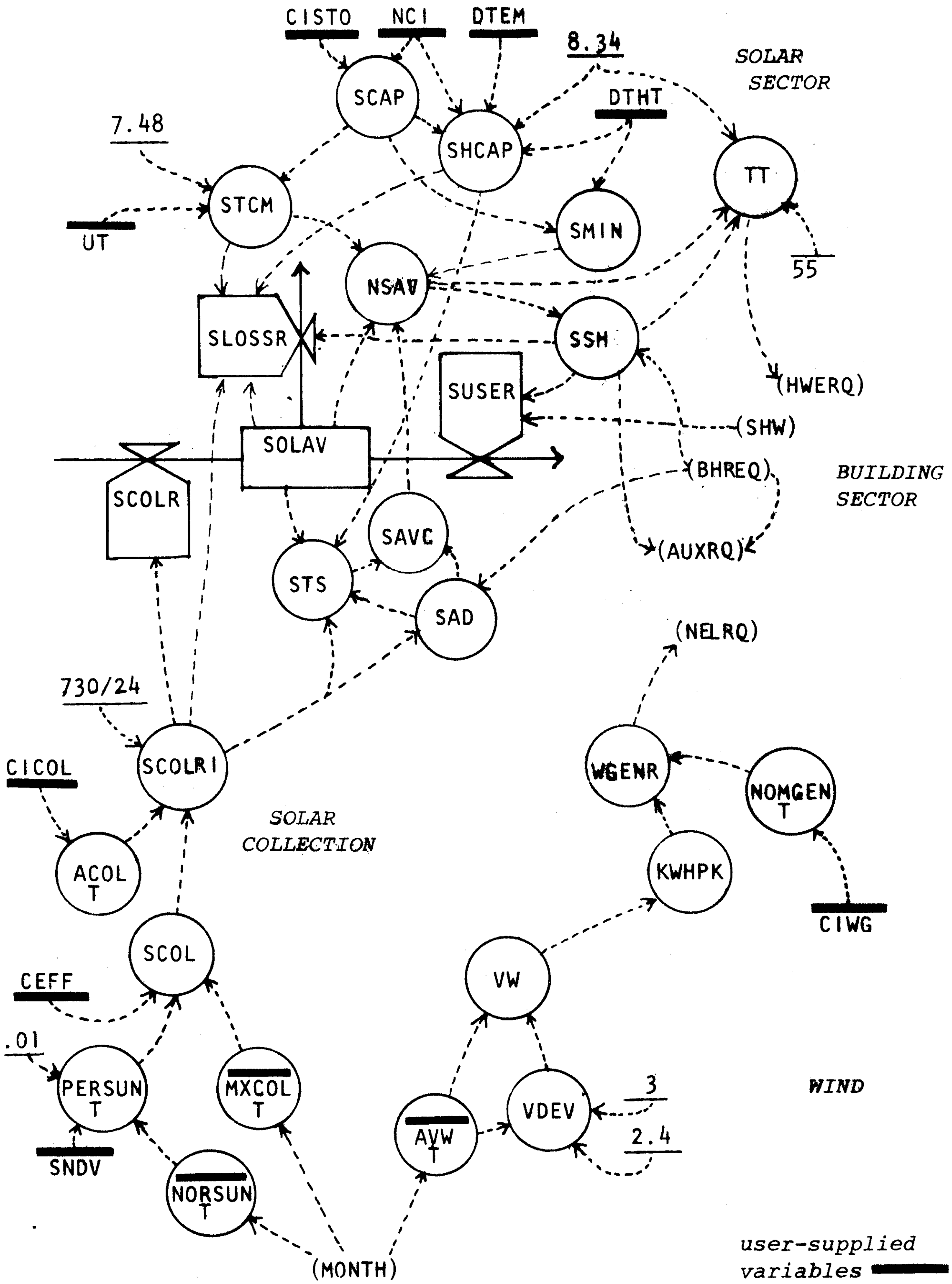
Solar Energy

The amount of solar energy collected is calculated from the area of the collector, the mean monthly percentage of possible sunshine, and the maximum possible solar radiation for the chosen location. The area of the collector is determined solely from the amount of capital invested in solar collection.

The driving force of the solar energy collection subsector consists of two user supplied table functions: MXCOL, which is the maximum possible daily radiation available on the specified collector surface, and NORSUN, which is the normal percentage of sunshine (See Fig. 8). Both of these factors must be supplied for the specific location in question and are plotted by month. This input is derived from appropriate weather or climatic data and handbooks (1, 2). A random process in the model (3) generates a present percentage of possible sunshine PERSUN (expressed as a decimal) which is multiplied by the maximum possible daily radiation MXCOL and by average collector efficiency CEFF to obtain the daily



Causal Loop Diagram for Solar and Wind and Building Energy Flow Sectors
Fig. 6



Solar and Wind Energy Flow Diagram
Fig. 7

collection rate per square foot of collector SCOL. Since rates used in the level equations in this model are expressed in monthly terms, a conversion is performed in the next step of the calculations by multiplying SCOL by the fraction 730/24 (4). SCOL is also multiplied by the area of the collector ACOL to obtain the indicated monthly rate of solar energy collection SCOLRI (This intermediary auxiliary equation is included, instead of going directly to the rate of collection SCOLR used in the level equations, because the quantity is used elsewhere in the model in another rate equation; the DYNAMO language does not permit the use of rates, except from the preceding computation interval, in rate equations).

Collector area ACOL is determined from the amount of capital invested in solar collection CICOL and is illustrated in Figure 9. Since there are as yet no real economies of scale in actual solar collectors, the slight decrease in unit cost evident from this table is due to the fact that the cost of the control mechanisms does exhibit some economy of scale. The unit cost levels off eventually, as the area must be zoned to work properly, and the collectors themselves have a finite base price.

The amount of solar energy which can be stored, for a given size of storage, is limited by the minimum temperature which can supply useful heat to the buildings, and by the maximum feasible collection temperature. In the community integrated system model the storage type is assumed to be water, although it would be possible to adjust parameters of storage to approximate the limiting temperatures and unit heat capacities of other types of storage.

There is a threshold value of energy SMIN which must be present in the storage for any useful heat to be available. In order to determine this value, a zero level of energy must be defined. In the model the zero level is that present at the equilibrium temperature of the storage, here taken as 55^{O}F, approximately the average of ground temperature and the inside temperature of the building TIN, since it is assumed that the storage is in contact with both (If the storage is isolated from heated structures, the equilibrium temperature must be chosen accordingly, i.e., if it is completely buried in the ground, the storage would equilibrate at ground temperature TG, which would be a variable). The threshold value of stored energy SMIN is therefore calculated from the difference DTHT between the minimum useful storage temperature (here 95^{O}) and the equilibrium temperature (55^{O}) times the unit heat capacity of the storage medium (8.34 Btu/gal-^{O}F for water) times the storage tank capacity SCAP. SCAP is derived from the capital investment in solar storage CISTO (Fig. 10). The unit cost of storage is taken in this table as about 27¢ per gallon form small storage tanks, levelling off at about 11¢ per gallon for tanks greater than 75,000 gallons; these figures are derived from rough estimates of solar storage costs at the low end of the scale and from costs of swimming pools at the upper end. They are probably representative of actual costs although the curve may level off too soon (5).

The maximum thermal storage capacity SHCAP is determined by the maximum temperature which can reasonably be attained by the collectors used (here 175^{O}F), and is calculated similarly to the threshold value of energy SMIN; storage capacity (in gallons) SCAP is multiplied by the unit heat capacity (8.34) and by the difference between the maximum reasonable storage temperature and the temperature at storage equilibrium. In the model this difference is the sum of DTHT and DTEM, known as the threshold

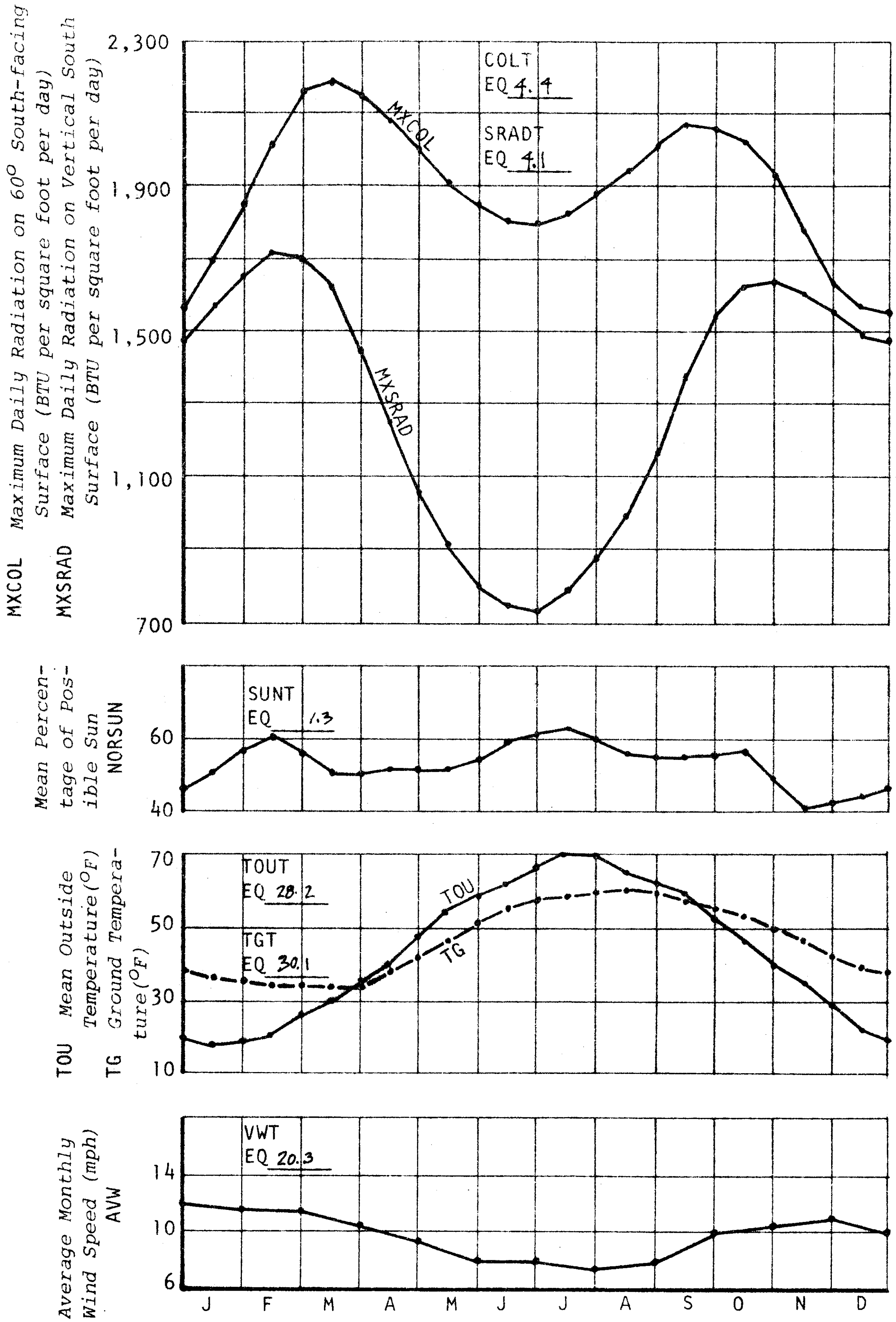

MXCOL Maximum Daily Radiation on 60° South-facing Surface (BTU per square foot per day)
MXSRAD Maximum Daily Radiation on Vertical South Surface (BTU per square foot per day)
2,300
1,900
1,500
1,100
700
COLT
EQ 4.4
SRADT
EQ 4.1
MXCOL
MXSRAD
Mean Percentage of Possible Sun NORSUN
60
40
SUNT
EQ 1.3
TOU Mean Outside Temperature (°F)
TG Ground Temperature (°F)
70
50
30
10
TOUT
EQ 28.2
TGT
EQ 30.1
TOU
TG
Average Monthly Wind Speed (mph) AVW
14
10
6
VWT
EQ 20.3
J F M A M J J A S O N D
MONTH

Fig. 8 (Ref. 11)

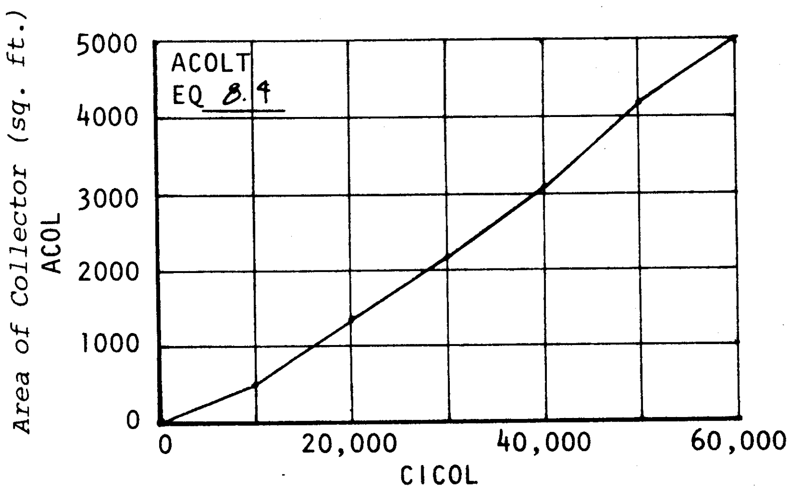
temperature range (or the difference between the equilibrium temperature and the minimum useful temperature) and the useful temperature range (or the difference between the minimum useful temperature and the maximum possible storage temperature), respectively. DTHT is given as 40° ($95^{\circ}F - 55^{\circ}F$) and DTEM as 75° ($170^{\circ}F - 95^{\circ}F$), but both can be altered by the modeller to represent specific situations. A maximum thermal storage capacity SHCAP must be provided in the model because the efficiency of the collector CEFF in the model is taken as an average efficiency (estimated from published data) for the collector temperature range chosen. An alternative method would have been to model collector efficiency as well, linking it to solar radiation and outside temperature, both of which can be found elsewhere in the model, and average collector temperature. With this method as collector temperature increased efficiency would drop, thus limiting the maximum energy collectable. The temperature corresponding to the maximum energy value of storage should be about 10 degrees (F) lower than the maximum collector temperature, unless precise data is available for a given system. The temperature of the storage tank TT after energy for space heating SSH is removed is calculated for hot water requirements HWERQ, and is discussed with the building energy flow sector.

Because the model uses an average collector efficiency CEFF, the rate of solar energy collection SCOLR can be greater than zero even when the temperature of the tank has reached its maximum realistic value. Unless the level of solar energy available in the storage SOLAV takes this extraneous collection into account, it would not represent the true amount of energy available. To prevent this misrepresentation, at each computation interval any excess of collection SCOLR plus energy in storage SOLAV over energy use SUSER and normal thermal losses SOLAV/STCM must be discarded. The equation for solar energy losses SLOSSR includes these excess capacity losses as well as the thermal losses. Heat will be lost from the solar storage as long as its temperature is greater than its equilibrium temperature; the rate of heat loss per month is the amount of energy in the storage SOLAV divided by the storage thermal time constant STCM. STCM is the perceived period of time in months for the storage to reach its equilibrium value, and is calculated from storage capacity SCAP and its thermal conductivity UT (6). SOLAV does not represent the total solar energy available at any given time, but is simply that available from the storage. Moreover, it is the amount of energy that is retained from one computation interval to the next; if the computation interval is large and the thermal time constant small, little or nothing will be carried over in storage.

The total amount of solar energy available for use NSAV during a given period includes energy available from collection SAVC as well as energy already in storage SOLAV. There are two reasons, one relating to model structure and one relating to reality, for allowing this to occur. If all the solar energy collected had to pass through the storage before being available for use, the energy collected in one computation interval could not be used until the next. While this might not be too inaccurate for very short intervals, unless the storage had a very large thermal capacity much of the energy collected might be discarded, due to the characteristics of the loss calculations in the model. The use rate would never have the opportunity to approach the collection rate, since use would be solely based on the energy in storage. Furthermore, it does not make sense, in most cases, to think of energy being collected in one week for use in the next. There seem to be two distinct economical sizes of solar heating systems; one has a relatively small thermal capacity capable of carrying over energy for two or three days, while the other is the concept of seasonal storage, with extremely large thermal capacity and heat typically being collected in the summer and fall for use several months later.

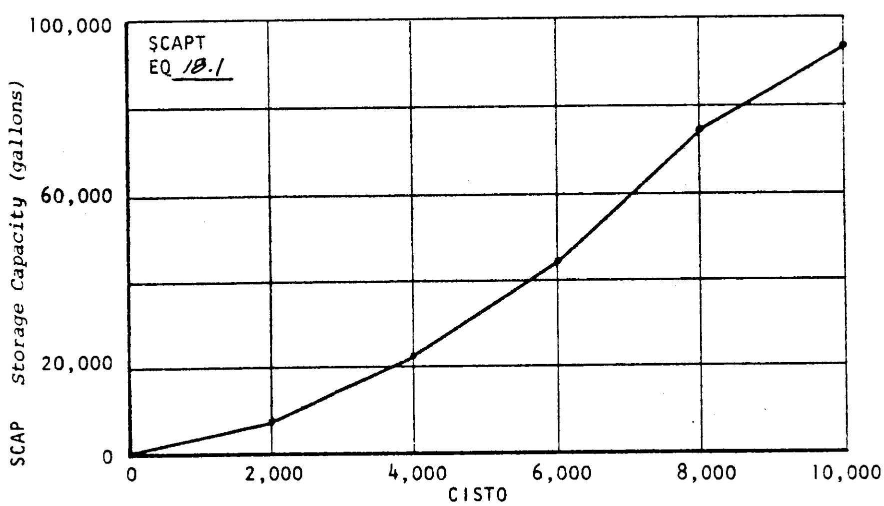
In real life a solar heating system would also have available the option of direct use of the energy as it is collected, a delay of minutes at most. It would not be realistic, however, always to allow the direct use of the entire amount of solar energy collected; if a collector is capable of providing enough energy for a whole day (or more, through storage) in a collection period of 8 or fewer hours, it is clear that some of the energy must be stored, if only temporarily. To take this into account, and to prevent the model from using energy that in reality would have been lost due to limited thermal capacity SHCAP, the equation for solar energy available from collection SAVC is separated into solar energy available directly SAD and solar energy which must be temporarily stored STS. SAD is the minimum of either the solar energy collected SCOLRI or one third of the building heat requirements BHREQ. This permits all energy collected to be used directly if the solar collection system is greatly undersized or if building heat requirements are extremely large. Solar energy which must be stored temporarily STS is the minimum of either the difference between solar collection SCOLRI and solar energy available directly SAD, or the difference between the thermal heat capacity of the storage SHCAP and the amount of energy in storage SOLAV. Thus, while not actually putting the collected energy into storage, the amount available for use SAVC is reduced, if necessary, by the excess capacity.

Although it is possible that extremely high energy demands would result in more room available in the storage, high demands would also have the effect of greatly increasing the amount of solar energy usable directly SAD and reducing the amount that would require temporary storage STS.



Capital Investment in Solar Collector ($)

Fig. 9



Capital Invested in Solar Storage (dollars)

Fig. 10

SOLAR ENERGY SECTOR

SOLAR ENERGY AVAILABLE

```
PERSUN.K=NORMRN(NORSUN.K,SNDV.K)*.01                        1, A
NORSUN.K=TABLE(SUNT,MONTH.K,0,12,0.5)                       1.2, A
SUNT=46/50/56/60/56/51/51/52/52/52/54/59/61/62/60/          1.3, T
  56/55/55/55/56/49/41/42/44/46
SNDV.K=FIFGE((100-NORSUN.K)/2.4,NORSUN.K/2.4,               1.5, A
  NORSUN.K,50)
    PERSUN - CURRENT % OF POSS SUN <1>
    NORSUN - MEAN % OF POSS SUN <1.2>
    SUNT   - AT 44 DEG N  71 DEG W <1.3>

MXSRAD.K=TABLE(SRADT,MONTH.K,0,12,0.5)                      4, A
SRADT=1480/1570/1660/1720/1700/1620/1450/1250/1060/         4.1, T
  920/810/760/740/800/880/1000/1170/1380/1550/1630/
  1640/1610/1560/1490/1480
MXCOL.K=TABLE(COLT,MONTH.K,0,12,0.5)                        4.4, A
COLT=1570/1690/1850/2010/2160/2190/2150/2080/2000/          4.5, T
  1920/1850/1810/1800/1830/1880/1940/2010/2060/
  2060/2020/1930/1780/1640/1570/1570
    MXSRAD - MAX CLEAR DAY SUN ON S WALL <4>
    SRADT  - BTU/SQ FT/DAY AT 44 DEG N <4.1>
    MXCOL  - MAX DAILY SUN ON 60DEG COL <4.4>
    COLT   - BTU/SQFT-DAY AT 44DEG N LAT <4.5>

SGAIN.K=PERSUN.K*MXSRAD.K                                   6, A
    SGAIN  - DAILY INCIDENCE ON S WALL (BTU/SQFT) <6>
    PERSUN - CURRENT % OF POSS SUN <1>
    MXSRAD - MAX CLEAR DAY SUN ON S WALL <4>
```

SOLAR STORAGE

```
SOLAV.K=SOLAV.J+DT*(SCOLR.JK-SUSER.JK-SLOSSR.JK)            7, L
SOLAV=SOLA                                                  7.2, N
SOLA=0                                                      7.3, C
    SOLAV  - ENERGY IN SOLAR STORAGE,  BTU <7>
    SUSER  - SOLAR ENERGY USE ,  BTU/MONTH <10>
    SLOSSR - SOLAR ENERGY LOSSES <17>
    SOLA   - SOLAR COLLECTION <7.3>

SCOLR.KL=SCOLRI.K                                           8, R
SCOLRI.K=SCOL.K*ACOL*(730/24)                               8.2, A
ACOL=TABXT(ACOLT,CICOL/NIC,0,60000,10000)*NIC               8.3, N
ACOLT=0/500/1333/2143/3077/4167/5000 SQFT                   8.4, T
CICOL=0 $                                                   8.5, C
NIC=1                                                       8.6, C
    SCOLRI - SOLAR ENERGY COLLECTION (BTU/MO) <8.2>
    SCOL   - BTU/SQ FT-DAY <9>
    ACOL   - COLLECTOR AREA (SQFT) <8.3>
    CICOL  - CAPITAL INVESTED IN SOLAR COLLECTOR <8.5>
    NIC    - NUMBER OF IDENTICAL COLLECTORS <8.6>
```

```
SCOL.K=PERSUN.K*MXCOL.K*CEFF                                  9, A
CEFF=.55                                                      9.1, C
    SCOL    - BTU/SQ FT-DAY <9>
    PERSUN  - CURRENT % OF POSS SUN <1>
    MXCOL   - MAX DAILY SUN ON 60DEG COL <4.4>
    CEFF    - AVERAGE COLLECTOR EFFICIENCY <9.1>
```

SOLAR ENERGY USE

```
SUSER.KL=SSH.K+SHW.K                                          10, R
    SUSER   - SOLAR ENERGY USE ,  BTU/MONTH <10>
    SSH     - SOLAR SPACE HEATING (BTU/MO) <11>
    SHW     - HW FROM STORAGE <32>

SSH.K=MIN(NSAV.K,BHREQ.K)                                     11, A
    SSH     - SOLAR SPACE HEATING (BTU/MO) <11>
    NSAV    - NET SOLAR AVAILABLE FOR SPACE HEATING (BTU/
                MO) <12>
    BHREQ   - BUILDING HEAT REQD (BTU/MO) <25>

NSAV.K=SAVC.K+(SOLAV.K/DT)-(SOLAV.K/STCM)-(SMIN/DT)  12, A
SAVC.K=SAD.K+STS.K                                            12.3, A
SAD.K=MIN(SCOLRI.K,BHREQ.K/3)                                 12.4, A
STS.K=MIN(SCOLRI.K-SAD.K,(SHCAP-SOLAV.K)/DT)                  12.5, A
    NSAV    - NET SOLAR AVAILABLE FOR SPACE HEATING (BTU/
                MO) <12>
    SAVC    - SOLAR AVAILABLE FROM COLLECTION <12.3>
    SOLAV   - ENERGY IN SOLAR STORAGE,  BTU <7>
    STCM    - STORAGE THERMAL TIME CONSTANT <17.2>
    SMIN    - THRESHOLD VALUE OF USEFUL SOLAR ENERGY
                <17.8>
    SAD     - SOLAR AVAILABLE DIRECTLY <12.4>
    STS     - SOLAR TEMP STORED <12.5>
    SCOLRI  - SOLAR ENERGY COLLECTION (BTU/MO) <8.2>
    BHREQ   - BUILDING HEAT REQD (BTU/MO) <25>
    SHCAP   - HEAT CAPACITY OF STORAGE,  BTU <17.7>
```

```
SLOSSR.KL=MAX(SCOLRI.K+(SOLAV.K/DT)-SSH.K-SHW.K-      17, R
  SHCAP,(SOLAV.K/STCM))
STCM=(10.4/UT)*EXP((1/3)*LOGN(MAX(SCAP/               17.2, N
  GALCF,1E-6)))/730
UT=.04 BTU/HR-SQFT-DEG(F)                             17.4, C
CISTO=0 $                                             17.5, C
NIS=1                                                 17.6, C
SHCAP=SCAP*CP*(DTEM+DTHT)*NIS                         17.7, N
SMIN=SCAP*CP*DTHT*NIS                                 17.8, N
SCAP=TABXT(SCAPT,CISTO/NIS,0,8000,2000) UNIT          17.9, N
SCAPT=0/7480/22960/55920/74800 GALLONS                18.1, T
DTEM=75 DEG(F)                                        18.2, C
DTHT=40 DEG(F)                                        18.3, C
CP=8.34 BTU/GAL-DEG(F)                                18.4, C
GALCF=7.48 GAL/CUFT                                   18.5, C
    SLOSSR - SOLAR ENERGY LOSSES <17>
    SCOLRI - SOLAR ENERGY COLLECTION (BTU/MO) <8.2>
    SOLAV  - ENERGY IN SOLAR STORAGE, BTU <7>
    SSH    - SOLAR SPACE HEATING (BTU/MO) <11>
    SHW    - HW FROM STORAGE <32>
    SHCAP  - HEAT CAPACITY OF STORAGE, BTU <17.7>
    STCM   - STORAGE THERMAL TIME CONSTANT <17.2>
    UT     - TANK THERMAL CONDUCTIVITY <17.4>
    EXP    - TOTAL ENERGY AND FOOD EXPENDITURES <139>
    SCAP   - STORAGE VOLUME <17.9>
    CISTO  - CAPITAL INVESTED IN STORAGE <17.5>
    NIS    - NUMBER OF IDENTICAL STORAGE TANKS <17.6>
    DTEM   - RANGE OF USEFUL TEMPERATURES <18.2>
    DTHT   - RANGE OF THRESHOLD TEMPERATURE <18.3>
    SMIN   - THRESHOLD VALUE OF USEFUL SOLAR ENERGY
               <17.8>

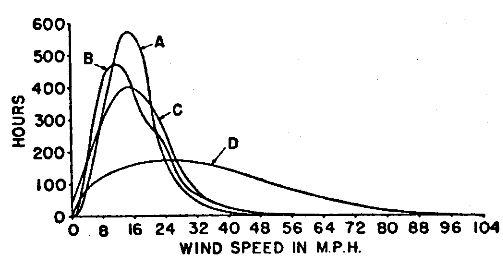
TT.K=((NSAV.K-SSH.K)/(SCAP*CP*NIS+1))+55              19, A
    TT     - TANK TEMP AFTER SPACE HEAT <19>
    NSAV   - NET SOLAR AVAILABLE FOR SPACE HEATING (BTU/
               MO) <12>
    SSH    - SOLAR SPACE HEATING (BTU/MO) <11>
    SCAP   - STORAGE VOLUME <17.9>
    NIS    - NUMBER OF IDENTICAL STORAGE TANKS <17.6>
```

Wind Energy

If after careful study of the wind regime and siting possibilities it is determined desirable to generate electricity from the wind on site, there are three possible ways to utilize the output. Utilization and efficiency would be at a peak if all the power generated could be used immediately, but this is often an unrealistic assumption since the wind sometimes blows strongly at night or at other times of limited demand. Surplus power could be stored as electricity in batteries, as heat in a water tank or other medium, or it could be fed through a synchronous inverter to a regional electrical network. The first of these proposals could be implemented at any site; the last two depend on the economic proximity of power lines (either to justify an expensive battery system or to make a connection with the inverter). A community of the size studied in this model should not find it uneconomical to make a connection to the regional grid, given the coverage in New England.

It would not be a simple matter to construct a model that would admit to the interchanging of these various methods of utilizing surplus wind power; the structure of each appears to be unique. For simplicity's sake it was decided to incorporate the use of synchronous inversion and connection to a regional power network as likely being the most economical and reliable system. The cost of electrical storage in batteries is high, and this has been a limiting factor in wind electrical utilization. Storage depletion in conjunction with a calm period is also a possibility which must not be overlooked; it must be assumed that a community of this size has a need for a certain degree of reliability in its power supply. At first, sensible heat storage appears to be a simple and economical solution, but this overlooks the fact that electrical energy is thereby immediately degraded to the lowest possible usable form of energy. Electricity would have to be purchased to meet the demand during periods of no wind as well. The use of a synchronous inverter simplifies the question of storage by eliminating it entirely. Full back up electricity would be available whenever needed, thus minimizing disruption due to equipment failure or an extended calm. Implicit in this choice, however, is the acknowledgement that the community is in part tied to a greater outside world.

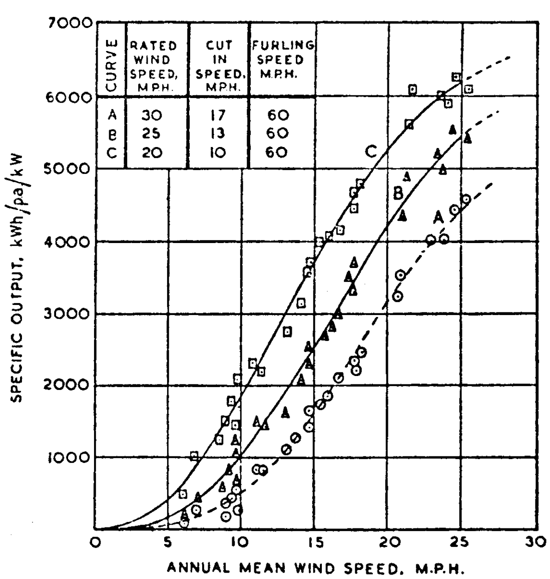
The actual model structure of the wind energy subsector is quite simple (Fig. 1). The amount of electricity generated WGENR is determined by the rated generator capacity NOMGEN (Fig. 14) and the unit monthly generator output KWHPK, which is a function of the average wind velocity VW. User supplied variables include the capital invested in wind generating capacity CIWG and the mean monthly wind velocities at the site in question AVW. In the calculation of average wind speeds (for the current computation interval) VW from AVW, the deviation of the averages from the mean VDEV was taken as 3 mph (7).



Velocity distribution of wind in New England; 5-year averages.
Curve A Blue Hill, mean annual velocity 18 miles an hour.
Curve B Nantucket, mean annual velocity 16 miles an hour.
Curve C Grandpa's Knob, mean annual velocity 17 miles an hour.
Curve D Mt. Washington, mean annual velocity 34 miles an hour.*

Fig. 11 Ref.(8)

Since wind velocities are not normally distributed (See Fig. 11) and since power in the wind is not linearly related to its velocity, it was not possible to calculate the available energy directly from the wind speed data most readily obtainable, i.e., mean wind speeds. Furthermore, the fact that the distribution of wind speeds is highly site specific (Fig. 11) makes it difficult to state the relationship between the mean wind speed and the power output as a general rule. As this relationship has been plotted from velocity distributions for a few cases (Fig. 12), it was decided to use one of the available curves to give the relation between average wind speed VW and the output per kilowatt of rated generator capacity KWHPK (Fig. 13). In actuality this data is also related to the site conditons, generator size, rated wind speed, and cut-in speed, so it may be desirable to derive the curve as much as possible from actual site measurements (this can be done easily in the model, since the data is input in tabular form).



Relationships between specific output and annual mean wind speeds

Fig. 12 Ref.(9)

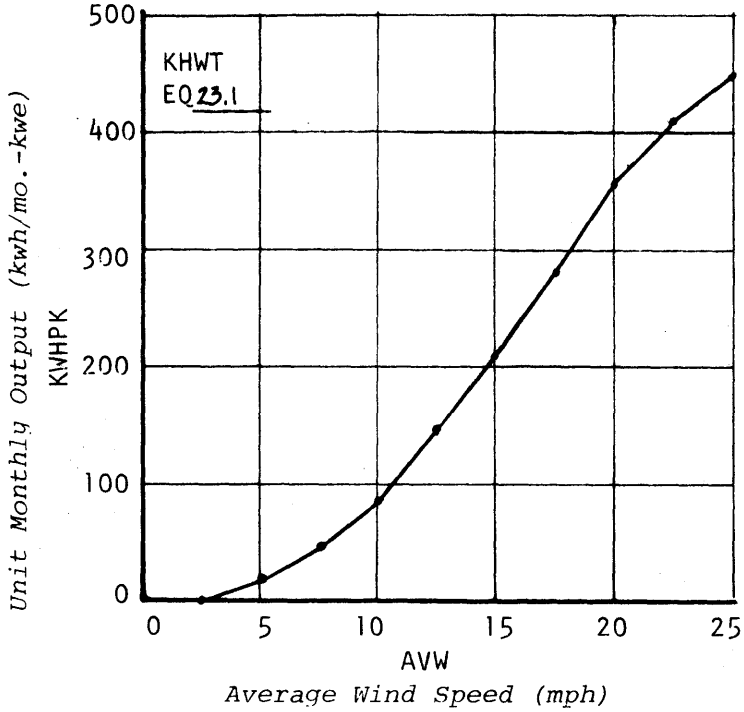


Fig. 13

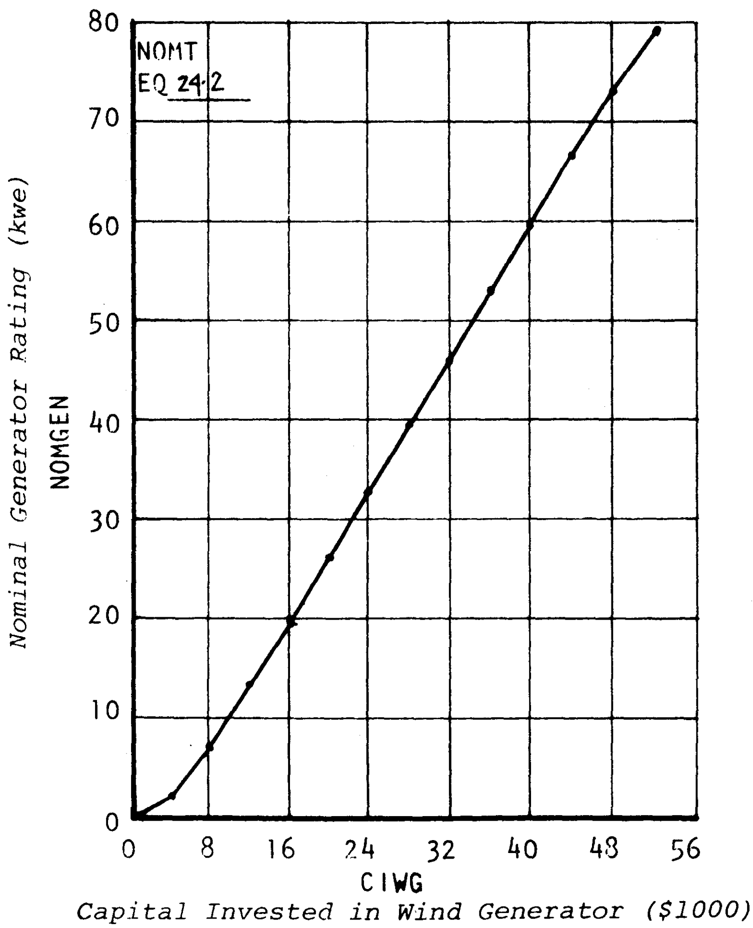


Fig. 14 Ref.(10)

WIND ENERGY

```
VW.K=NORMRN(AVW.K,VDEV.K)                                20, A
AVW.K=TABLE(VWT,MONTH.K,0,12,1)                          20.2, A
VWT=12/11.5/11.5/10.5/9.5/8/8/7.5/8/10/10.5/11/10        20.3, T
  MILES/HOUR
VDEV.K=(AVW.K+3)/2.4                                     20.5, A
    VW     - CURRENT AVERAGE WIND SPEED (MPH) <20>
    AVW    - MONTHLY WIND SPEED (MPH) <20.2>
    VDEV   - DEVIATION OF WIND FROM NORMAL <20.5>
    VWT    - (AVERAGE OF PORTLAND AND EASTPORT) <20.3>

KWHPK.K=TABHL(KWHT,VW.K,2.5,25,2.5)                      23, A
KWHT=0/16/45/83/145/210/280/355/410/445 KWH/MO-KWE       23.1, T
    KWHPK  - UNIT  MONTHLY OUTPUT (KWH/MO-KWE) <23>
    VW     - CURRENT AVERAGE WIND SPEED (MPH) <20>

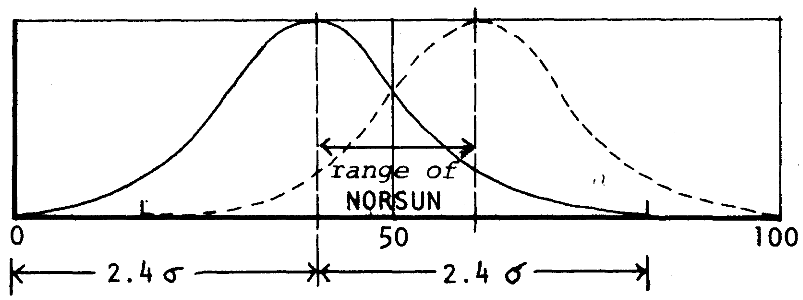
WGENR.K=KWHPK.K*NOMGEN*NIW                               24, A
NOMGEN=TABXT(NOMT,CIWG/NIW,0,52000,4000) NOMINAL         24.1, N
NOMT=0/2/7/13.3/19.9/26.4/32.9/39.5/46.1/52.8/59.3/      24.2, T
  66.5/73/79 KWE
CIWG=0 $                                                 24.3, C
NIW=1                                                    24.4, C
    WGENR  - ELECTRICITY GENERATED, KWH/MO <24>
    KWHPK  - UNIT  MONTHLY OUTPUT (KWH/MO-KWE) <23>
    NOMGEN - GENERATOR RATING <24.1>
    NIW    - NUMBER OF IDENTICAL WIND GENERATORS <24.4>
    CIWG   - CAPITAL INVESTMENT IN WIND PLANT <24.3>
```

(For complete citations, please refer to the Bibliography)

1 NOAA, Climatic Atlas.

2 ASHRAE Handbook of Fundamentals, Chapter 22.

3 For convenience, the percentage of sunshine PERSUN was considered to be normally distributed around the mean monthly percentage of possible sunshine NORSUN. The function DYNAMO uses to create random numbers in a normal distribution, NORMRN, will not create any numbers greater than 2.4 standard deviations; this is not critical for the use of the data, since over 98% of occurrences in a normal distribution lie within this range. The percentage of possible sunshine in real life cannot exceed 100 or drop below 0, but can take any value in between. The choice of standard deviation of sunshine SNDV reflects these limitations; it is determined from the difference between the normal percentage of sunshine NORSUN and 100%, or from the difference between NORSUN and 0%, whichever is the least. For the model this means that when NORSUN is less than 50%, there will be no instances where PERSUN can reach 100%; conversely, when NORSUN is greater than 50%, there will be no times when PERSUN is 0%. Since the amount of energy collectable is linearly related to the amount received (unlike the wind speed cubed - power relationship) this should have little effect on the model.



Percent of Possible Sunshine

4 The occasional use of the ratio 730/24 to convert daily data to monthly data is simply due to the desire to avoid a decimal. For the purposes of this model the year of 365 days is divided into 12 equal months of 730 hours each; thus one month equals 30.416666... days, or 730/24.

5 These values are derived in part from discussion of solar storage costs by Professors Thornton and Pratt in their course on Solar Energy Systems at MIT in Fall 1976. As this data is presented in tabular form in the model it is easily alterable by the user.

6 The storage thermal time constant STCM is derived from both the thermal capacity and thermal resistance of the storage tank. The basic formula for the thermal time constant in hours is

$$STCM = C_T \times R_T \text{ hours, where}$$

$C_T = V_{CF} \times 7.48 \times 8.34$ thermal capacity in Btus/^{o}F,

V_{CF} = volume of tank in cubic feet,

$R_T = 1/(U \times SA)$ thermal resistance in Fr-sqft-^{o}F/Btu,

U = overall heat transfer coefficient,

SA = tank surface area, in square feet,

7.48 = gallons/cu ft, and

8.34 = Btu/lb-^{o}F.

If the volume in question approximates a cube, surface area is related to volume by the following equation

$$SA = 6 \times V^{2/3}$$

If this is substituted into the formulas, above, STCM reduces to

$$STCM = (10.4 \times V^{1/3})/\ U \text{ hours.}$$

It is this equation, converted to months, which has been translated into DYNAMO.

7 Proceeding on the assumption that wind speed averages vary little from the long term means, the deviation was set at 3 mph. There may be differences between deviations on a daily basis as compared to deviations on a weekly or monthly basis, and these differences may be critical to the choice of computation interval, but this possibility was not investigated.

8 Putnam, p 61.

9 Golding, *The Generation of Electricity by Wind Power,* p 156.

10 The values in Figure 14 were derived from manufacturer's prices for the under 10 kwe range, and were extrapolated to a unit cost of about $600-700 per kwe in the upper range.

11 The weather values used in Figure 8 represent conditions at a location halfway between Portland and Augusta, Maine, except for the wind speeds, which are an average of Portland and Eastport.

b

Waste-Biogas Sector

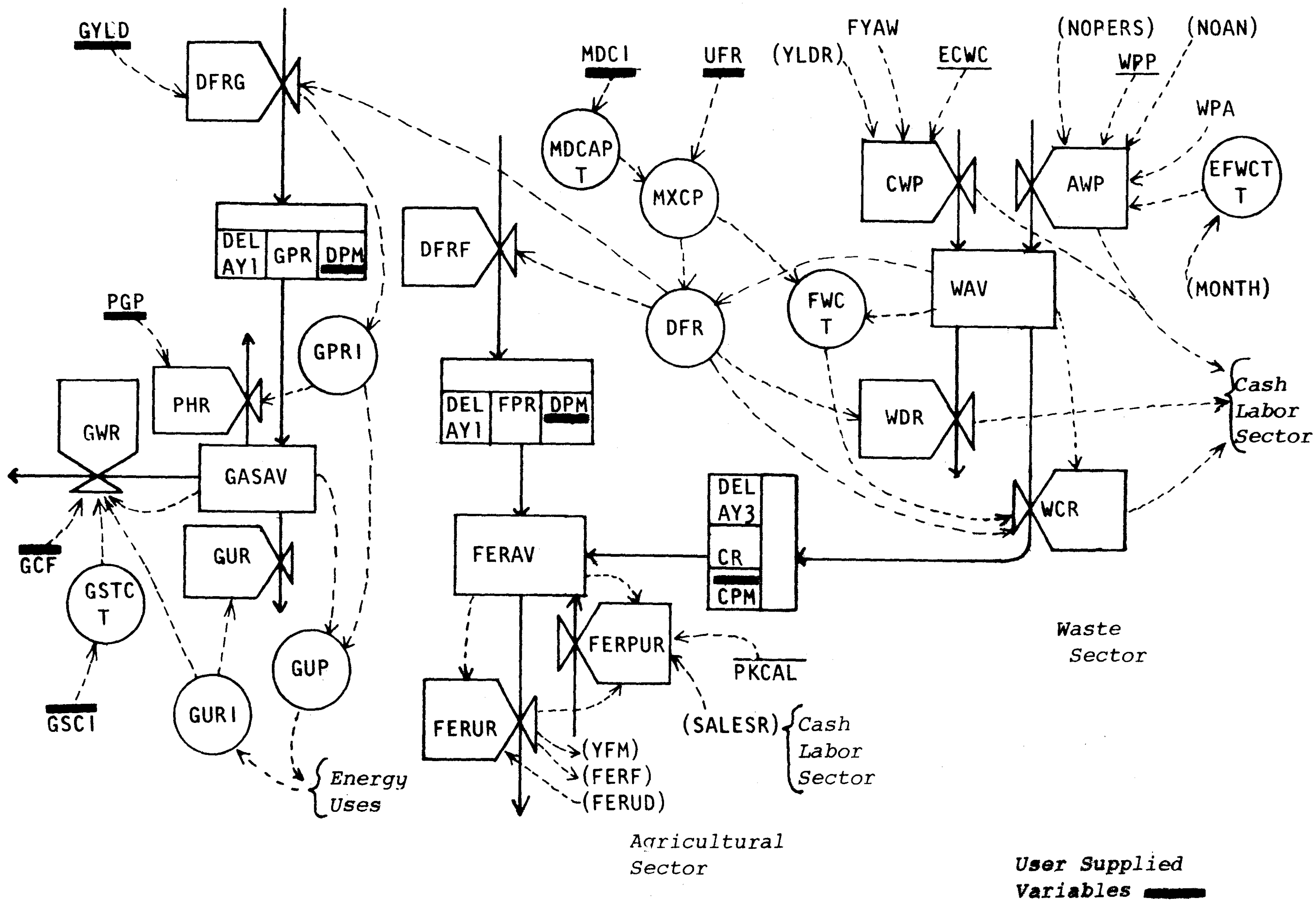
WASTE-DIGESTER SECTOR

Both fertilizer and a usable gas can be produced in a biogas digester. For an agricultural community this is nearly an ideal situation since it will have enough waste available to make a biogas plant an economical proposition. Furthermore, although waste can be composted or plowed under, the gasses of decomposition are lost to the atmosphere, more labor is required, and the nutrient quality of the resulting product is not as high a quality as digested waste (1). Necessary components of a complete biogas system include the means of collecting and storing waste, the actual digester, a gas holder and a means for storing digested fertilizer.

The waste-digester sector is arguably the most important sector of the community integrated system as it furnishes the essential links in the ecological cycle of production and consumption (See Figs. 15 and 19). Thus the model is tied in one way or another to most of the other sectors of the model. Waste comes primarily from the agricultural sector, to which both fertilizer and fuel are returned. Biogas also plays a part in the building energy sector, while capital investment ties it to the cash-labor sector. Labor is also necessary to manage the various processes in the sector. The following paragraphs examine in detail the three parts of the sector - waste handling, fertilizer production, and gas production.

Waste Handling

Because its nutrients are important to the agricultural side of the community, waste is conserved in the model. The major limiting factors in digester operation are the amount of waste available WAV and the capacity of the digester MDCAP. The amount of waste available is calculated



Waste-Biogas Sector Flow Diagram
Fig. 15

from the user supplied constants for the number of people NOPERS and animals NOAN in the community, as well as from crop yields YLDR (from the agricultural sector). The amount of volatile dry solids produced per person WPP is estimated as 7 lbs /month, while the waste produced per animal is 250 lbs /month (2). These factors are modified by three more user supplied parameters, the efficiency of crop waste collection ECWC, the fraction of yields as waste FYAW, and the efficiency of collection of animal waste EFWC, which has a seasonal variation depending on the degree of animal confinement (3, Fig. 16). Labor and dollar costs of handling waste are discussed with the cash-labor sector, although it should be noted here that somewhat more labor is required for composting than for digestion. It is assumed that storage for waste before digestion, space for composting, and storage for fertilizer produced is available at no additional capital cost in the usual farm structures or outside. The capital cost of human waste collection should be included in the capital cost of the building sector, since the presence of a biogas digester does not necessarily imply costs beyond the alternative methods of waste handling. The capacity of the digester MDCAP depends on the amount of capital investment in the digester MDCI supplied by the user (4, Fig. 17).

As waste accumulates, the amount available WAV is compared to the input capacity of the digester MXCP to determine the amount of waste which can be incorporated into the digester, known as the digester feed rate DFR. For the purposes of this model, which assumes a digester operating in the mesophilic temperature range (85 - 105°F), the unit feed rate UFR was taken as 6 lbs dry waste/cuft of digester capacity/month (5). Since no waste is discarded, if the input capacity MXCP is insufficient to

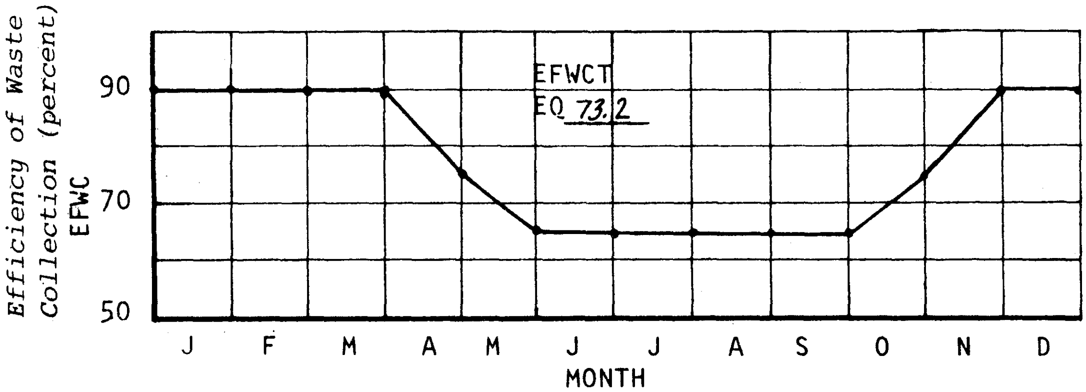


Fig. 16

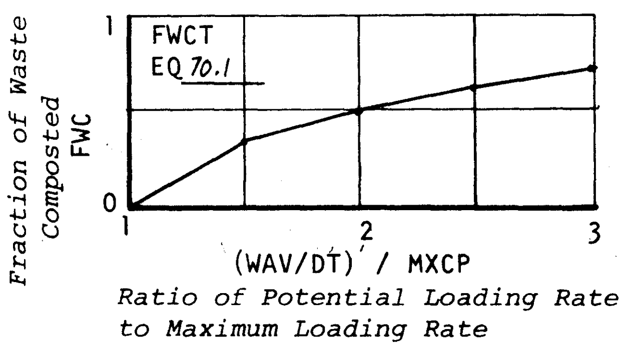


Fig. 16b

accommodate all the available waste WAV some of the surplus is composted WCR. The fraction of the available waste composted FWC depends on the general trend of waste supply compared with the digester feed rate DFR so as to avoid any great accumulation of waste and also to assure a supply of waste so that the digester operates near capacity (Fig. 16b).

Fertilizer Production

Fertilizer can be produced in two ways, either in the digestion process or by composting. The digester feed rate DFR is used to determine the material flow through the digester in terms of fertilizer; in this model the weight of fertilizer produced is considered to be approximately equal to the dry weight of the waste fed to the digester. The fertilizer production rate from digested waste FPR is a delayed function of the digester feed rate in terms of fertilizer DFRF. For a gas conversion efficiency of about 60% and a feed rate of DFR of 6 lbs./cuft-mo, a one-month detention period DPM is sufficient (6). The production of fertilizer from composting CR is also a delayed function, but of the rate of composting waste WCR; the composting period CPM is taken as four months. Fertilizer available FERAV is thus increased by both composting CR and digestion FPR of waste; it is also increased by purchases of fertilizer FERPUR necessary to replenish nutrients lost when crops are sold. The absence of investment in a digester MDCI will also result in fertilizer being purchased. FERAV is decreased by both fertilizer use on crops FERUR and on hayfields FERHF, both inputs from the agricultural sector.

Gas Production

Gas production GPR is determined in much the same way as fertilizer, except that it is calculated in terms of cubic feet of gas. The unit yield

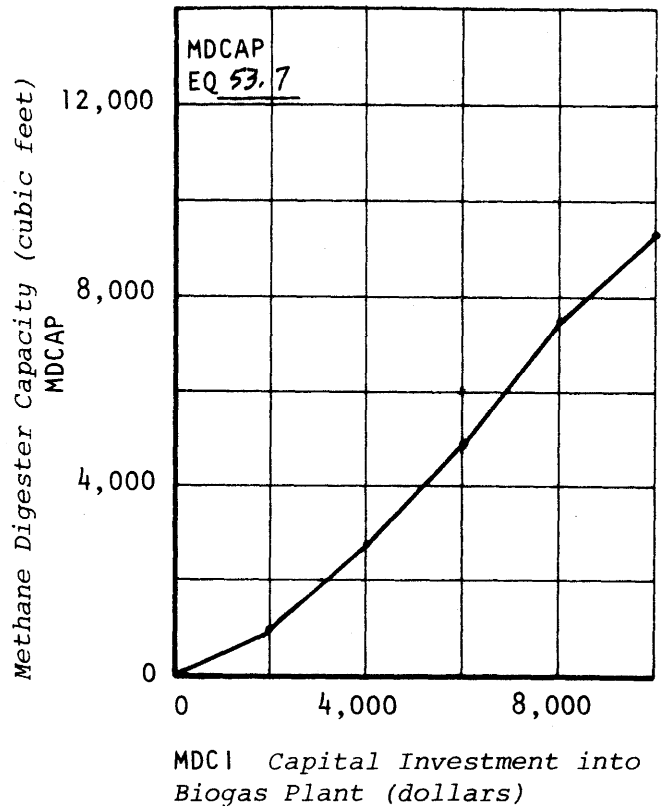

MDCAP
EQ 53.7
12,000
8,000
4,000
0
Methane Digester Capacity (cubic feet)
MDCAP
0
4,000
8,000
MDCI Capital Investment into
Biogas Plant (dollars)

Fig. 17

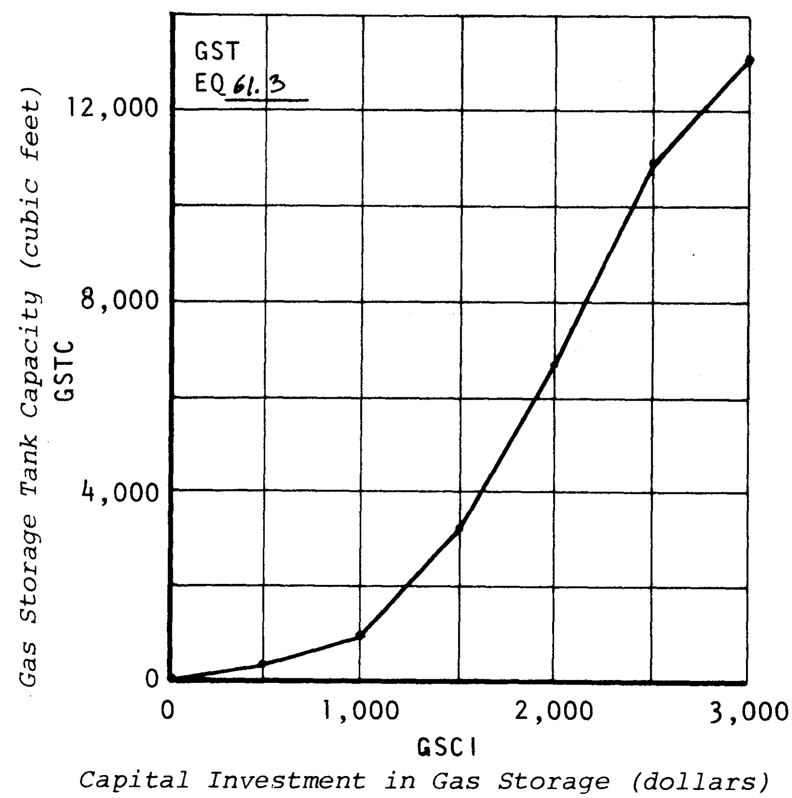

GST
EQ 61.3
12,000
8,000
4,000
0
Gas Storage Tank Capacity (cubic feet)
GSTC
0
1,000
2,000
3,000
GSCI
Capital Investment in Gas Storage (dollars)

Fig. 18

of gas from dry waste GYLD is assumed to be 8 cubic feet per pound for a conversion efficiency of 60% and a detention period DPM of one month (7). There are two limitations to gas availability GASAV which are not present for fertilizer production: one is the gas storage capacity, which is the product of the actual size of the storage tank GSTC and a factor for compression of the stored gas GCF. GSTC is determined from the investment in gas storage GSCI, supplied by the user, who also supplies the compression factor GCF, which is equal to 100 at a pressure of about 1500 psi (8, Fig. 18).

The second limitation in gas production is the amount of gas required to maintain process temperatures PHR, which is calculated as a percentage PGP of gas production GPR. In this model it is assumed that 15% of gas production is necessary to maintain the proper temperature for digestion (9). If a greater amount of gas is produced GPR than is either used in the community GUR or in maintaining the temperature in the digester PHR, it must be stored. If there is not enough room in the storage tank for all the gas, then some or all of it must be discarded; this is called the gas waste rate GWR in the model, although in actuality the gas could be used for process heat rather than discarded (5).

WASTE/BIOGAS-FERTILIZER SECTOR

FERTILIZER

```
FERAV.K=FERAV.J+DT*(FPR.JK+CR.JK+FERPUR.JK-            50, L
  FERUR.JK-FERHF.J)
FERAV=FER                                              50.2, N
FER=0 LBS                                              50.3, C
    FERAV   - TOTAL FERTILIZER USE (LBS/MO) <50>
    FPR     - FERTILIZER PRODUCED IN DIGESTER, LBS/MO
                <52>
    CR      - FERTILIZER PRODUCED FROM COMPOST, LBS/MO
                <55>
    FERPUR - FERTILIZER PURCHASES (LBS/MO) <108>
    FERUR   - FERTILIZER USE FOR CROPS <102>
    FERHF   - FERTILIZER USED ON HAYFIELDS <51>

FERHF.K=MIN(FERAV.K/DT,FERHFD)                         51, A
FERHFD=NOAN*FPAF                                       51.1, N
FPAF=330 LBS/ACRE                                      51.2, C
    FERHF   - FERTILIZER USED ON HAYFIELDS <51>
    FERAV   - TOTAL FERTILIZER USE (LBS/MO) <50>
    FEPHFD - FERT DESIRED FOR HAYFIELDS <51.1>
    NOAN    - NUMBER OF ANIMALS <87.2>

FPR.KL=DELAY1(DFRF.JK,DPM)                             52, R
DPM=1 MONTH                                            52.1, C
    FPR     - FERTILIZER PRODUCED IN DIGESTER, LBS/MO
                <52>
    DFRF    - DIGESTER LOADING IN TERMS OF FERTILIZER,
                LBS/MO <53>
    DPM     - DETENTION PERIOD <52.1>

DFRF.KL=DFR.K                                          53, R
DFR.K=MIN(MXCP,WAV.K/DT)                               53.2, A
MXCP=MDCAP*UFR*NID                                     53.4, N
UFR=6 LBS/CUFT-MO                                      53.5, C
MDCAP=TABXT(MDCAPT,MDCI/NID,0,8000,2000)               53.6, N
MDCAPT=0/1000/3000/6000/10000 CUFT                     53.7, T
MDCI=0 $                                               53.8, C
NID=1                                                  53.9, C
    DFRF    - DIGESTER LOADING IN TERMS OF FERTILIZER,
                LBS/MO <53>
    DFR     - WASTE  DIGESTED (LBS/MO) <53.2>
    MXCP    - MAXIMUM DIGESTER LOADING, LBS/MO <53.4>
    WAV     - DRY WASTE AVAILABLE LBS <71>
    MDCAP   - DIGESTER CAPACITY <53.6>
    UFR     - UNIT LOADING RATE <53.5>
    NID     - NUMBER OF IDENTICAL DIGESTERS <53.9>
    MDCI    - CAPITAL INVESTED IN BIOGAS PLANT <53.8>

CR.KL=DELAY1(WCR.JK,CPM)                               55, R
CPM=4 MONTHS                                           55.1, C
    CR      - FERTILIZER PRODUCED FROM COMPOST, LBS/MO
                <55>
    CPM     - COMPOSTING PERIOD <55.1>
```

GAS

```
GASAV.K=GASAV.J+DT*(GPR.JK-PHR.JK-GUR.JK-GWR.JK)     56, L
GASAV=GAS                                            56.1, N
GAS=0 CUFT                                           56.2, C
    GASAV  - GAS AVAILABLE, CUFT <56>
    GPR    - GAS PRODUCTION, CUFT/MO <58>
    PHR    - PROCESS HEAT (CUFT/MO) <57>
    GUR    - GAS USE (CUFT/MO) <62>
    GWR    - GAS WASTED (CUFT/MO) <61>

PHR.KL=GPRI.K*PHP                                    57, R
PHP=.15                                              57.1, C
    PHR    - PROCESS HEAT (CUFT/MO) <57>
    GPRI   - GAS PRODUCTION INDICATED <58.2>
    PHP    - PERCENT OF OUTPUT FOR HEAT <57.1>

GPR.KL=GPRI.K                                        58, R
GPRI.K=DELAY1(DFRG.JK,DPM)                           58.2, A
    GPR    - GAS PRODUCTION, CUFT/MO <58>
    GPRI   - GAS PRODUCTION INDICATED <58.2>
    DFRG   - DIGESTER LOADING IN TERMS OF GAS, CU FT/MO
               <60>
    DPM    - DETENTION PERIOD <52.1>

DFRG.KL=DFR.K*GYLD                                   60, R
GYLD=8 CUFT/LB                                       60.1, C
    DFRG   - DIGESTER LOADING IN TERMS OF GAS, CU FT/MO
               <60>
    DFR    - WASTE  DIGESTED (LBS/MO) <53.2>
    GYLD   - GAS YIELD PER LB DRY SOLIDS <60.1>

GWR.KL=MAX((GPRI.K*(1-PHP))+(GASAV.K/DT)-GURI.K-     61, R
  (GSTC*GCF)/DT,0)
GSTC=TABXT(GST,GSCI/NIT,0,2500,500)*NIT              61.2, N
GST=0/270/1000/3200/6680/10960 CUFT                  61.3, T
GSCI=0 $                                             61.4, C
GCF=100                                              61.5, C
NIT=1                                                61.6, C
    GWR    - GAS WASTED (CUFT/MO) <61>
    GPRI   - GAS PRODUCTION INDICATED <58.2>
    PHP    - PERCENT OF OUTPUT FOR HEAT <57.1>
    GASAV  - GAS AVAILABLE, CUFT <56>
    GSTC   - STORAGE TANK  SIZE <61.2>
    GCF    - GAS COMPRESSION FACTOR(1500 PSI) <61.5>
    GSCI   - INVESTMENT IN STORAGE TANK <61.4>
    NIT    - NUMBER OF IDENTICAL TANKS <61.6>
```

```
GUR.KL=GURI.K                                               62, R
GURI.K=GUF.K+GUE.K+GUC.K                                    62.2, A
GUF.K=FUS.K*CFG                                             62.3, A
GUE.K=GENR.K*CFK                                            62.4, A
GUC.K=GEUS.K/(BTUF*.8)                                      62.5, A
    GUR     - GAS USE (CUFT/MO) <62>
    GUF     - GAS USED FOR FUEL (CUFT/MO) <62.3>
    GUE     - GAS USED FOR ELECTRICITY (CUFT/MO) <62.4>
    GUC     - GAS USED FOR COOKING (CUFT/MO) <62.5>
    FUS     - (GAL/MO) <113>
    CFG     - BIOGAS-GASOLINE CONVERSION <113.3>
    GENR    - ELECT FROM BIOGAS (KWH/MO) <35>
    CFK     - BIOGAS-ELECTRICITY CONVERSION (25%) <37.1>
    GEUS    - ENERGY FROM GAS (BTU/MO) <41>

GUP.K=(GPRI.K*(1-PHP))+(GASAV.K/DT)                         67, A
    GUP     - GAS USE POSSIBLE (CUFT/MO) <67>
    GPRI    - GAS PRODUCTION INDICATED <58.2>
    PHP     - PERCENT OF OUTPUT FOR HEAT <57.1>
    GASAV   - GAS AVAILABLE, CUFT <56>
```

WASTE

```
CWP.KL=YLDR.JK*FYAW*ECWC/1800                          68, R
FYAW=1.25 FRACTION                                     68.1, C
ECWC=.8                                                68.2, C
    CWP    - CROP WASTE PRODUCTION, LBS/MO <68>
    YLDR   - CROP YIELD (KCAL/MO) <89>
    FYAW   - OF YIELD AS WASTE <68.1>
    ECWC   - EFFICIENCY OF CROP WASTE COLLECTION <68.2>

WDR.KL=DFR.K                                           69, R
    WDR    - WASTE USE IN DIGESTER <69>
    DFR    - WASTE  DIGESTED (LBS/MO) <53.2>

FWC.K=TABHL(FWCT,(WAV.K/DT)/(MXCP+1E-6),1,3,0.5)       70, A
FWCT=0/.33/0.5/0.61/0.7                                70.1, T
    FWC    - FRACTION COMPOSTED <70>
    WAV    - DRY WASTE AVAILABLE LBS <71>
    MXCP   - MAXIMUM DIGESTER LOADING, LBS/MO <53.4>

WAV.K=WAV.J+DT*(AWP.JK+CWP.JK-WDR.JK-WCR.JK)           71, L
WAV=WA                                                 71.1, N
WA=0                                                   71.2, C
    WAV    - DRY WASTE AVAILABLE LBS <71>
    AWP    - ANIMAL WASTE PRODUCED, LBS <72>
    CWP    - CROP WASTE PRODUCTION, LBS/MO <68>
    WDR    - WASTE USE IN DIGESTER <69>

AWP.KL=(NOPERS*WPP)+(NOAN*WPA*EFWC.K)                  72, R
WPP=7                                                  72.1, C
WPA=250                                                72.2, C
    AWP    - ANIMAL WASTE PRODUCED, LBS <72>
    WPP    - LBS/MO TOTAL SOLIDS, <72.1>
    NOAN   - NUMBER OF ANIMALS <87.2>
    WPA    - LBS/MO     WASTE PER ANIMAL UNIT <72.2>
    EFWC   - EFFICIENCY OF ANIMAL WASTE COLLECTION <73>
```

```
EFWC.K=TABLE(EFWCT,MONTH.K,0,12,1)*.01                          73, A
EFWCT=90/90/90/90/75/65/65/65/65/65/75/90/90                    73.2, T
    EFWC    - EFFICIENCY OF ANIMAL WASTE COLLECTION <73>

WCR.KL=WCRI.K                                                   75, R
WCRI.K=(WAV.K-(DFR.K*DT))*FWC.K                                 75.2, A
    WCRI    - DRY WASTE COMPOSTED <75.2>
    WAV     - DRY WASTE AVAILABLE LBS <71>
    DFR     - WASTE  DIGESTED (LBS/MO) <53.2>
    FWC     - FRACTION COMPOSTED <70>

LABMD.K=DFR.K*HLD                                               76, A
HLD=FIFGE(.0025,.0015,CIELG,0)                                  76.1, N
    LABMD   - DIGESTER LABOR <76>
    DFR     - WASTE  DIGESTED (LBS/MO) <53.2>
    HLD     - UNIT RATE OF DIGESTER LABOR (HRS/LB) <76.1>
    CIELG   - INVESTMENT IN GAS ELECTRICAL GENERATOR
                <35.5>

LABCM.K=MIN(LAVCM.K,WCRI.K*HLC)                                 78, A
LAVCM.K=LAVW.K-LABW.K                                           78.2, A
HLC=FIFGE(.0002,.002,CIAM,1500)                                 78.3, N
    LABCM   - COMPOSTING LABOR (HRS/MO) <78>
    LAVCM   - LABOR AVAIL FOR COMPOSTING (HRS/MO) <78.2>
    WCRI    - DRY WASTE COMPOSTED <75.2>
    HLC     - UNIT RATE OF COMPOST LABOR (HRS/LB) <78.3>
    LAVW    - LABOR AVAILABLE FOR WOODCUTTING (HRS/MO)
                <48.2>
    LABW    - WOODCUTTING LABOR (HRS/MO) <48>
    CIAM    - INVESTMENT IN AGRICULTURAL MACHINERY
                <116.2>
```

WASTE-DIGESTER SECTOR NOTES

(For complete citations, please refer to the Bibliography)

1 Fry and Merrill, p 25.

2 Fry and Merrill, p 14. The animals in the model are all dairy cattle; if other types of animals are desired, either the model could be modified to accept them, or the equivalent number of cattle could be used with the present structure.

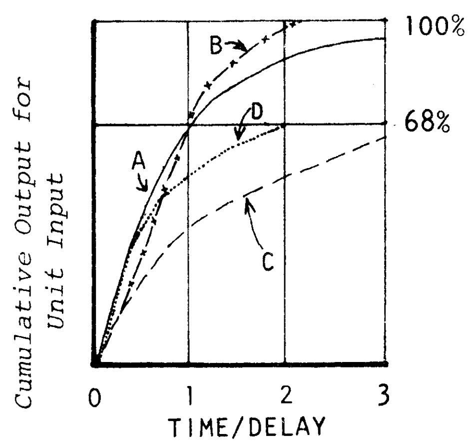
3 The table EFWCT shows a maximum recoverable waste of 90% during the time of year when the animals are likely to be confined all day, while the low of 65% in the summer assumes that they will be indoors at least part of the time and also that some of the manure will be collected from outside although the urine will be lost. The table is specific for northern New England - other parts of the country would have different confinement patterns.

4 The table MDCAPT is derived from information presented in Prasad et al, p 1355, giving the amounts of steel and cement required for different sizes of digesters. The digesters described, of 5000, 140, and 60 cu ft/day gas output, and 8200, 230, and 100 cu ft actual size, required 8.2, .4, and .2 metric tons of steel and 20, 1, and .5 metric tons of cement, respectively. The authors stated that the material costs were 40% of the cost of the total biogas plant, and that the digester itself plus the necessary piping represented 65% of that total. An estimated cost for construction steel of $500/metric ton and $93/metric ton for cement (including sand and gravel costs) (Means 1974 construction data inflated to 1977), results in digester costs of $8700, 430, and 215, respectively. Although the material costs have been calculated for the United States, the original cost breakdown was made for India, so there is a possibility that the resulting digester costs are too low. On the other hand, the sizes of the digesters were determined for a low gas yield of 3 cu ft/lb dry solids, whereas it is quite possible to obtain gas yields of 8 cu ft/lb without too much difficulty, and the digesters could be proportionately smaller. If the table is considered to relate investment to gas generating capacity instead of actual capacity, the costs may not be too far off.

5 Makhijani and Poole, p 153. Although incorporating the use of greater amounts of gas to be able to operate the digester at higher temperatures, resulting in increased feed rate and decreased detention period, would add more feedback to the model, it was decided to forgo this complexity for several reasons. Fry and Merrill, p 10, state that the higher temperatures are harder to maintain (although waste heat from an electrical generator would solve this problem), that the bacteria which live at these temperatures are extremely sensitive to any changes in their environment, and that most materials are easily digested in the normal range anyway. The most important reason from an agricultural point of view, however, is the fact that the resulting sludge is a poorer quality fertilizer than that produced at the lower temperatures.

6 Makhijani and Poole, p 149. If the digester were operated in the thermophilic range (120 - 140°F) it would be possible to lower the detention period, but it is probably undesirable to operate in that range for fertilizer production since it is said to produce a poorer quality fertilizer (Fry and Merrill, p 10). The gas yield per pound of waste also increases if the digester operates in the thermophilic range.

7 Makhijani and Poole, pp 146-9. The cumulative output of the DELAY1 function in the DYNAMO language is only 68% of the input at the delay time specified (curve A in Figure below), and reaches 93% in three delay periods. This corresponds well to actual gas output from dry waste, if the delay period is taken at one month (curve B; from Jakhijani and Poole p 147); the cumulative output is about 60 - 70% at this point for the digester conditions described and reaches its maximum sometime after 2 months. Real conditions corresponding to this model structure imply an indefinite detention period of waste in the digester. An actual digester, however, would be operated with a detention period of only one month; this corresponds to a gas yield of about 60 - 70% of the total possible. Structuring the model to reflect this conversion efficiency, by multiplying either input to or output from the DELAY1 function by .65, in conjunction with a delay time of one month (presumably corresponding to the detention period), would result in a cumulative output which only reached the reduced total output value after 3 months (curve C), rather than in the one month actual detention period desired. One way to make the cumulative output curve more closely approach the actual output would be to reduce the delay time used in the DELAY1 function to one half the actual digester period (curve D). Doing this, however, might require the use of a smaller computation interval DT in order to obtain acceptable accuracy. Since it is expected that the digestion process in the integrated system will be continuous, the difference between the real life output curve (B) and the DELAY1 output curve (C) is probably not a critical issue in the model because as soon as a steady state is reached the rate of output would be the same in either case.



8 Makhijani and Poole, p 157. The table GST is derived from a cost figure supplied by these authors for a 14,800 cu ft cylindrical pit with a reinforced concrete roof costing $3/sq ft, as well as from estimated costs of water storage for solar collectors. It is possible that these figures are too low, especially for high pressure storage, but they are servicable. The gas compression factor GCF is used to calculate the total volume of gas that can be stored at 1500 psi in one cubic foot and is derived from Boyle's Law, $PV/T = P'V'/T'$.

9 Makhijani and Poole, p 158, suggest that heat requirements when digesters are operated at mesophilic temperatures are unlikely to exceed 5 - 10% of total energy output. Fry and Merrill, p 24, on the other hand, state that 20 - 30% of the energy output is necessary to maintain the digester temperature in a temperate climate. The 15% required PGP in the model is taken as a compromise, and also reflects the probability that the digester will be built as part of a barn or greenhouse complex, rather than in an isolated position. Makhijani and Poole, p 157, also state that 80% of the heat loss in conventional sewage digesters is through the metal gas holder; if storage is separated from the digester or is insulated, the loss will greatly decrease.

C

Agricultural Sector

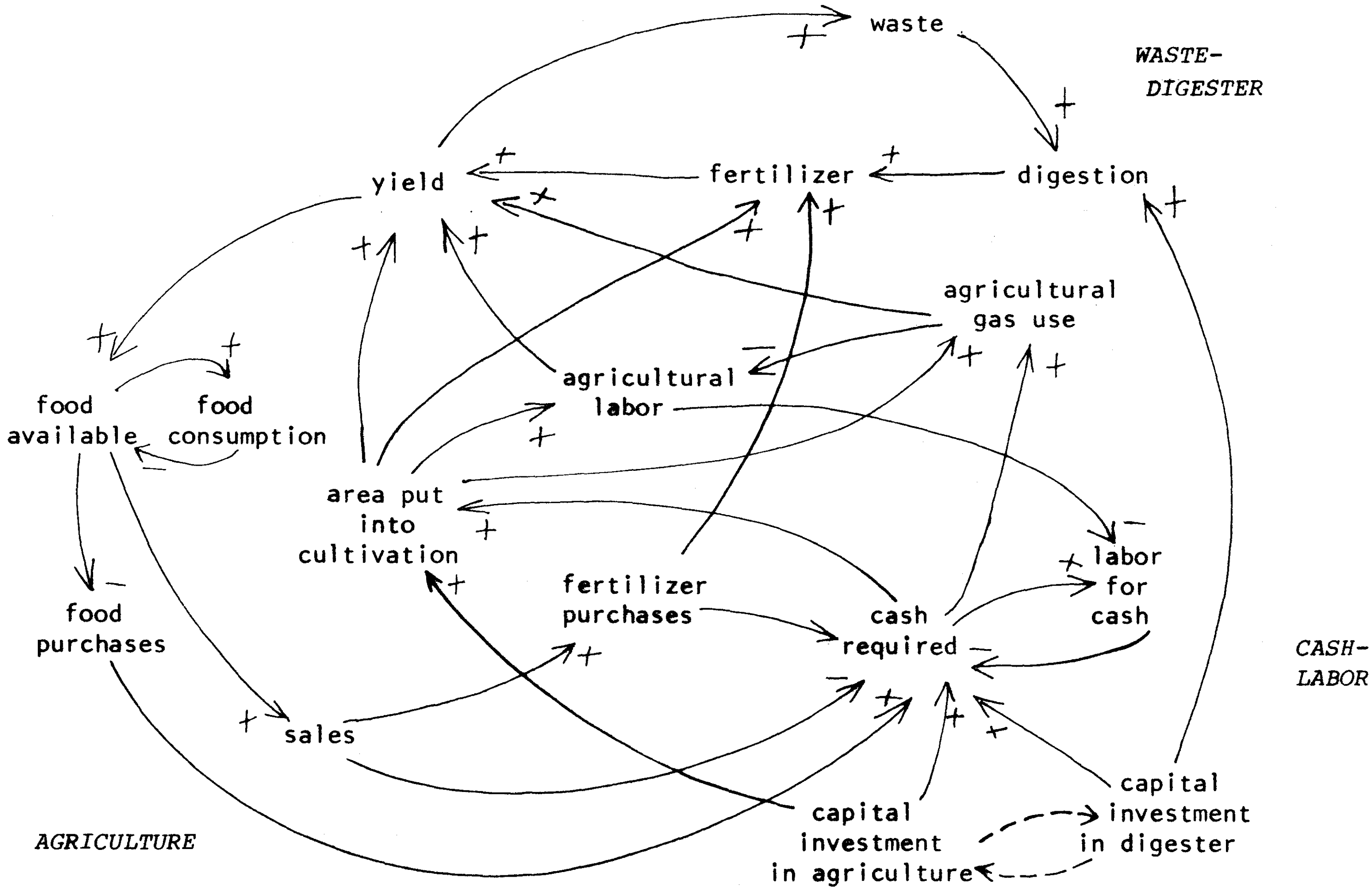
AGRICULTURAL SECTOR

The agricultural sector contains the equations relating to both food production and consumption. Food consumption is directly related to food availability and such parameters as the number of people and animals in the community, but food production also involves more complex relationships between the amount of fertilizer and fuel used and the amount of agricultural labor performed. Limiting factors in food production include the amount of labor and land area available, diminishing returns for fertilizer and fuel inputs, and finite available quantities of fertilizer and fuel; the agricultural sector relies heavily on the waste-biogas sector to produce these inputs, and they must be purchased if there is no digester provided. Figure 19 illustrates the relationships between these sectors and the Cash-labor sector, while Figure 20 details the relationships within the agricultural sector. The following sections describe the elements of the sector, beginning with food production from crops which predominates.

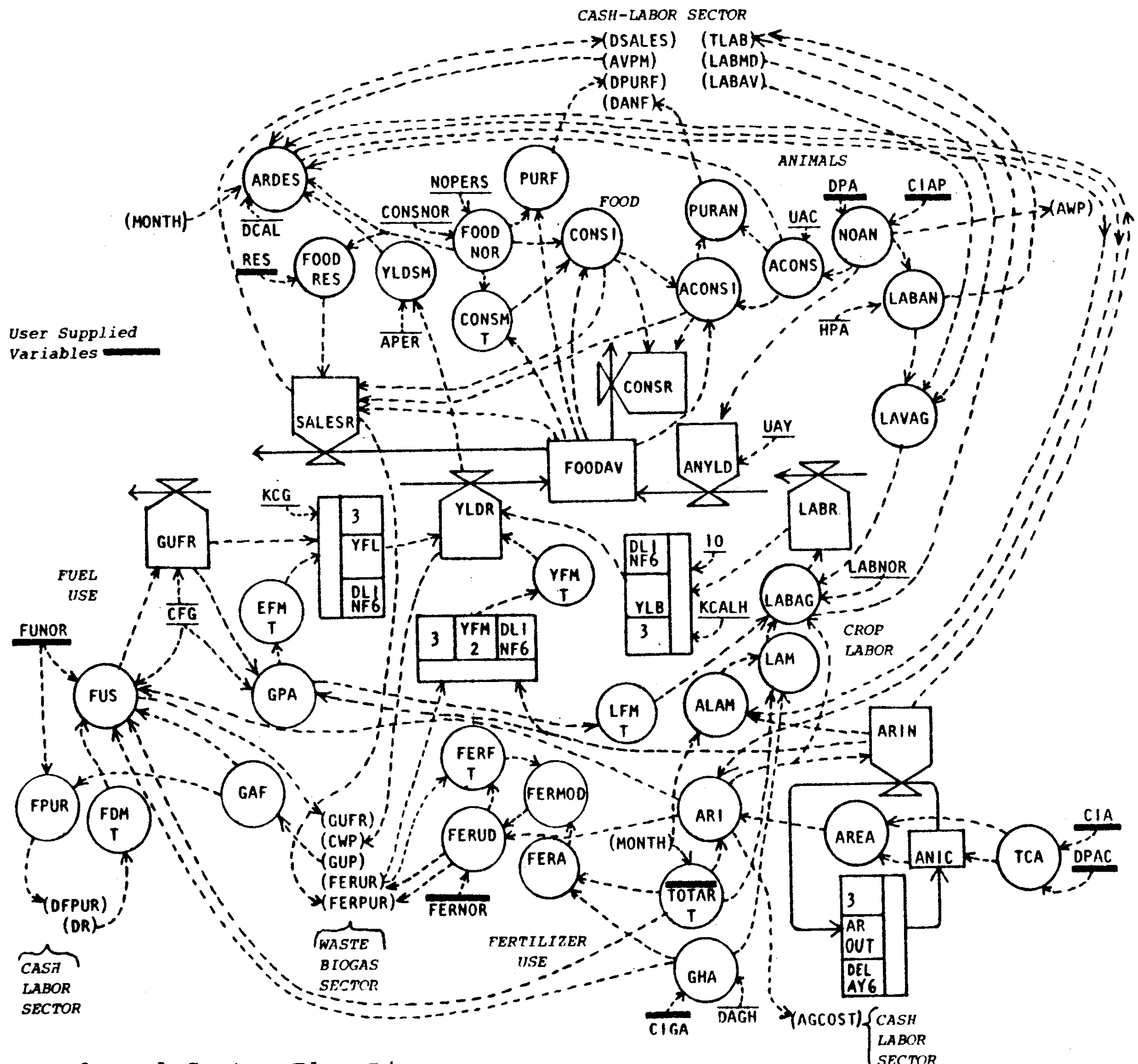
Food Production

Throughout this sector food production and consumption is discussed in terms of kilocalories. Although protein, minerals, and vitamins are all necessary components of diet, they do not as readily lend themselves to modelling as functions of energy inputs; the studies of the food system on which I have relied, consistently use kilocalories (1-3). It should be noted that the Food calorie is equivalent to 1000 small caolries, or one kilocalorie, thus the use of kilocalories in this context is convenient.

The derivation of reasonable assumptions for the relationships between different energy inputs and yields was one of the most difficult tasks in the creation of the model. Although much attention has recently been



Causal Loop Diagram for Agricultural Sector, Waste-digester Sector,
and Cash-Labor Sector
Fig. 19



Agricultural Sector Flow Diagram
Fig. 20

focussed on energy use in agriculture (4), in particular pointing out the diminishing returns to increasing energy usage, the effects of specific inputs are not well documented. These relations must be extrapolated from the confusing mass of data. As an example, there are curves available which relate the amount of fertilizer used to increased yield, but it is not made clear if the increases are also related to changes in other energy inputs (5,6). In modern agricultural systems actual labor accounts for less than .2% of total energy inputs (7), thus it might be expected that other inputs would predominate in affecting yield, but since the .2% is absolutely necessary for there to be any yield at all it is difficult to assign a specific value to it. In the absence of any real controls necessary to properly isolate the effects of the different inputs, I have attempted to do this by trial and error, until I have arrived at a set of assumptions which produces more or less reasonable results (8), taking into account only labor, fuel, and fertilizer use; these assumptions are outlined later in this section. The equation relationship of crop yield rate YLDR to agricultural inputs is the sum of the yield due to labor YLB and the yield due to fuel use YFM, multiplied by a fertilizer usage factor YFM. There are certainly many more aspects to agriculture than these, but these are the most critical and basic inputs.

Although agricultural input requirements are usually distributed somewhat throughout the growing season, this distribution is difficult to model exactly; since 1/2 to 3/4 of the inputs are required near the beginning (for ground preparation, fertilizing, planting, and initial cultivation), the model approximates this by requiring all inputs then. One drawback to this is that it ignores the importance of having sufficient labor at harvest time, although with mixed production there really is no great peak labor demand. The yield rate YLDR is a delayed function of the respective labor, fuel, and fertilzier inputs, with an average delay time of three months (9).

Labor

Energy inputs in the form of human labor are assumed to result in a return of ten times the energy value of the labor. Primitive agriculture in New Guinea and rice culture in the Philippines is reported to have energy outputs about 16 - 17 times greater than inputs (10), while for traditional Chinese smallholdings and English allotment gardens the return is reported to be 54 and 6 times inputs, respectively (11). It is perhaps unrealistic to assume that the energy inputs in these examples are all labor; the Chinese, for instance, use great amounts of manure and human waste, which may account for their extremely high rate of return, while in the slash-and-burn agriculture of New Guinea the ashes serve as fertilizer (although they are only effective for about a year). Some manure is probably used in the Philippines, and the English allotment garden probably uses manure or artificial fertilizer as well. An energy return of ten times input is probably conservative, however (12).

In the model, agricultural labor LABAG is determined by the area being put into cultivation ARI and is limited by the amount of labor available for agriculture LAVAG, since labor for animals LABAN and for the digester LABMD have top priority. The normal unit labor input LABNOR is 50 hours/acre; although this is high compared to certain modern cropping systems with 10 or fewer hours per acre, it is a reasonable figure for mixed farming and assumes a minimum fuel use GPA of 10 gallons/acre and digester fertilizer use of two tons per acre. The amount of agricultural labor is also modified if fuel use decreases; the modifier LFM increases the labor by a factor of 11 when there is no fuel use (Fig. 21). This represents, for instance, the situation in a greenhouse, where it is impossible to use machinery. A more detailed discussion of the substitution of human labor by fuel usage will be found in the section on fuel inputs. One other factor influences agricultural labor; a comparison of the area that is desired to be put into cultivation ARDES (in order to achieve desired yields) with the area that is possible to put into cultivation at a given time (affected by the season TOTAR (Fig. 26) and area already in cultivation AREA) results in an increased labor input if all the area desired cannot be cultivated. This modifer LAM will increase labor inputs by a maximum factor of five. If the area cultivated ARI is only that of the greenhouse GHA, however, LAM is limited to 2.5 since the fuel modifier LFM is 11 in that case (Fig. 21a).

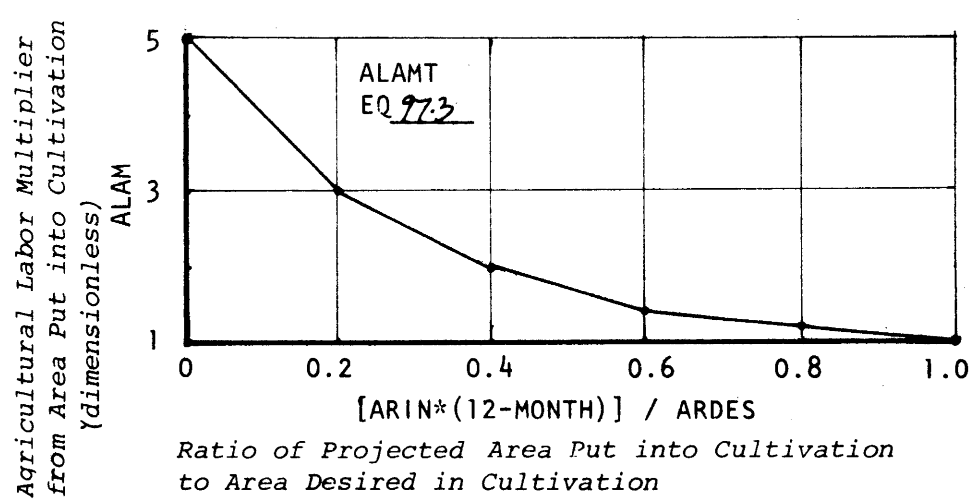


Fig. 21a

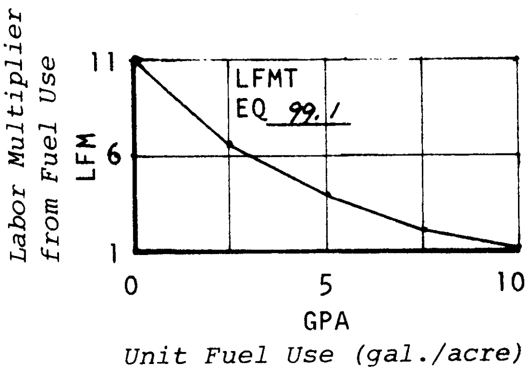


Fig. 21

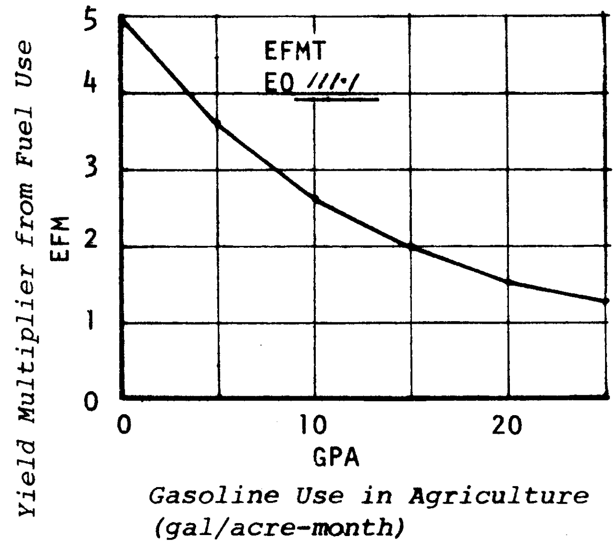


Fig. 22

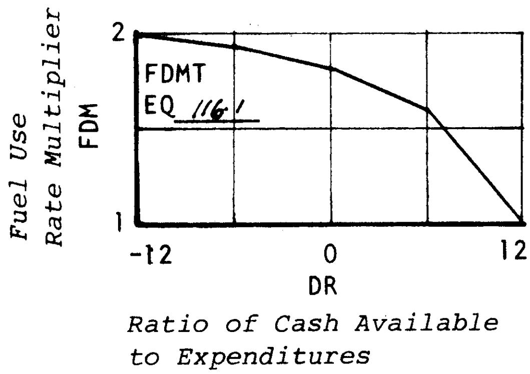


Fig. 23

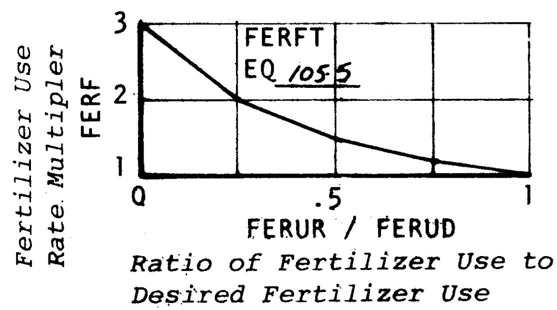


Fig.25

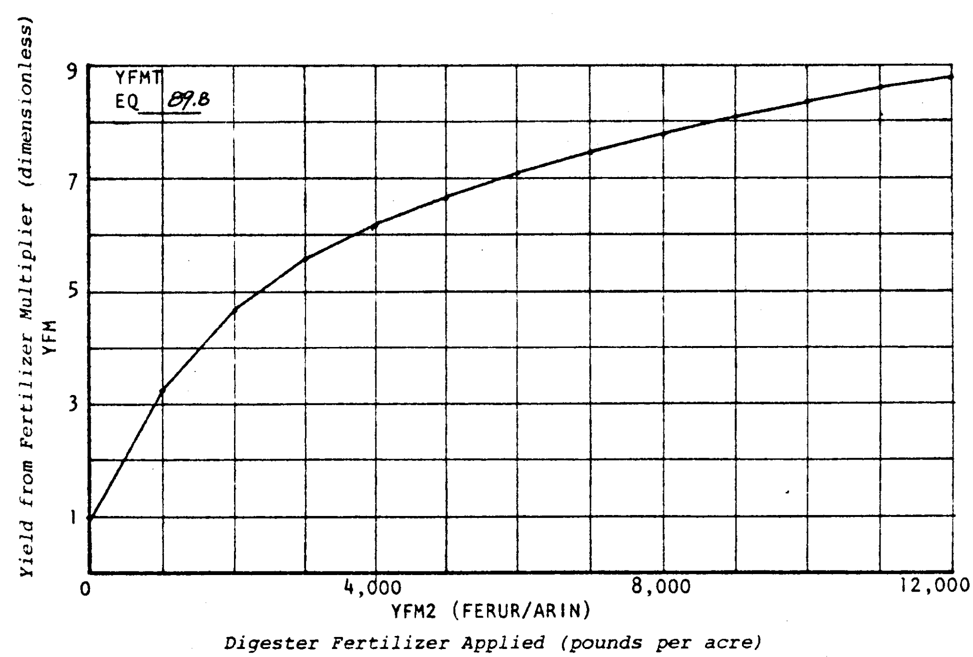


Fig. 24

Fuel Use

The yield from fuel use YFL is a delayed function of the amount of fuel used GUFR, the effectiveness of that fuel use EFM, and the energy content of the fuel KCG (13). To a certain extent, fuel can serve as a substitute for human labor in agriculture. The exact relationships between the amounts of fuel used, human labor required, and yield to be expected from given inputs are not well established, but presumably they could be expected to exhibit diminishing returns for increased fuel use. Figure 22 is intended to represent the effectiveness of fuel use in producing yield EFM, depending on the amount of fuel used per acre GPA (in gallons). This is at best a rough approximation, since the substitution of equal amounts of fuel for different tasks would not always result in the saving of equal amounts of labor (14). It can be safely assumed, however, that the most arduous labor would be the first to be replaced by the use of fuel; thus the greatest returns per unit of fuel consumption would be found at the lowest usage rates. The normal fuel use rate FUNOR corresponding with the normal labor input LABNOR of 50 hrs/acre was set at ten gallons of gasoline per acre. If fuel use per acre GPA drops below this value, it is reasonable to expect that it would have to be made up in labor, thus the labor multiplier LFM increases the desired amount of labor whenever GPA is less than 10, to a maximum of 11 times the usual amount (Fig 21, 15).

The actual amount of fuel used in agriculture GUFR is the sum of fuel use from gas available from the waste-digester sector FUS and purchased fuel FPUR. Fuel will be purchased if the supply from the digester GAF is consistently less than the desired fuel use based on the normal usage FUNOR and the area being put into cultivation ARI. Agricultural uses of digester-produced fuel have top priority, therefore, fuel available for agriculture GAF is equal to the maximum gas use possible GUP times CFG, which converts cubic feet of digester gas (GUP) to its energy equivalent in gasoline (GAF); CFG is 250 cu ft/gal (16). Provided that there is enough fuel available, fuel use can be increased in order to obtain increased yields; the fuel use modifier FDM depends on the expense ratio DR, which is the ratio of cash available to average expenses and is used with FDM to increase yields, and indirectly, the amount of cash available (Fig 23). The model is structured in such a manner as to prohibit any fuel use if the amount of land that can be cultivated TOTAR is equal to or less than the greenhouse area GHA; this acknowledges the difficulty of using machinery in a greenhouse and assures that greenhouse agriculture will be labor intensive. A final restriction of fuel use in agriculture is the amount of investment in agricultural machinery CIAM. Obviously, if CIAM is zero, there can be no fuel use, but CIAM must also be related to the total area being cultivated. Since there are many forms this relation can take, it is left to the user to assign values to CIAM and MCIAM (the minimum required amount of investment in machinery) corresponding to the amount of land farmed and the type of operation planned.

Fertilizer Use

Fertilizer alone cannot produce crop yields; energy must be supplied to make it available and to apply it. Thus, fertilizer simply enhances the energy yields inherent in agricultural albor and fuel use; like fuel use it also results in diminishing returns as more is applied. Data for this relationship (despite the lack of control on other inputs) are available.

The fertilizer yield multiplier YFM is adopted from published data (Fig 24, 17). When no fertilizer is applied, YFM = 1 and crop yields are due only to the labor and fuel inputs (and inherent soil fertility). Using six tons of fertilizer per acre increases yields almost nine times over the inherent fertility. The normal fertilizer use FERNOR is 4000 lbs/acre (18). In order for the yield multiplier YFM to correspond with the area on which the fertilizer was used, YFM, like the other agricultural yield multipliers, is a sixth order delay of the rate of fertilizer application per acre (FERUR/ARIN).

The amount of fertilizer used FERUR depends on the desired application FERUD and on how much fertilizer is left after fertilizer required for hay fields FERHF is taken from the general supply of fertilizer FERAV. FERUD is in turn determined by the product of the normal application FERNOR, any modifiers to the normal FERMOD, and the area of application ARIN. If the area that can be cultivated at a given time TOTAR is only that of the greenhouse, the desired amount of fertilizer is increased by a factor of three (FERA). Fertilizer use can also be increased by a modifier which compares previous fertilizer usage FERUR with that previously desired FERURD; if less than the normal amount has been applied, this modifier FERF increases the current desired use by up to a factor of three (Fig 25). Since the equations for the fertilizer yield multiplier YFM do not give any increased yield for fertilizer applications above 1200 pounds per acre, FERMOD limits the combined effect of FERA and FERF to a maximum of three times the normal application of FERNOR of 4000 pounds per acre.

Crop Area

Crop area is conserved in the model, that is to say it is neither created nor destroyed; it must either be in cultivation or not in cultivation at any given time. The total cultivable area TCA in acres is determined by the user supplied parameters for total investment in agriculture CIA and the cost per acre DPAC ($300/acre has been for farmland in New England). TCA serves as the initial value for the level ANIC, which represents the area not incultivation or, in other words, the area available for cultivation. The user must also supply the values for TOTAR, a table which relates the available crop area to the limitations of the seasons (Fig 26). In general, the maximum value of TOTAR, occurring in the summer months, is the total crop area TCA, while the minimum value for the winter months, is the greenhouse area GHA. GHA is also determined by user inputs for investment CIGA and unit greenhouse cost DAGH, here taken as $100,000/acre (about $2.50/sq ft). TOTAR should also be entered to limit the amount of area which can be put into cultivation in the early spring as well, since realistically there are only a few crops which can be planted then. While a monoculture is certainly a possibility, it is assumed that the integrated systems community is engaging in mixed cropping, since one of its purposes is to feed itself.

The amount of area which is put into cultivation ARIN is determined by comparing what is desired to be cultivated ARDES with the area which can actually be planted. This area is limited by the amount already in cultivation AREA and the season (through the table TOTAR). AREA is the difference between the total crop area TCA and the area not in cultivation ANIC. Assuming that a given area is occupied by one crop for three

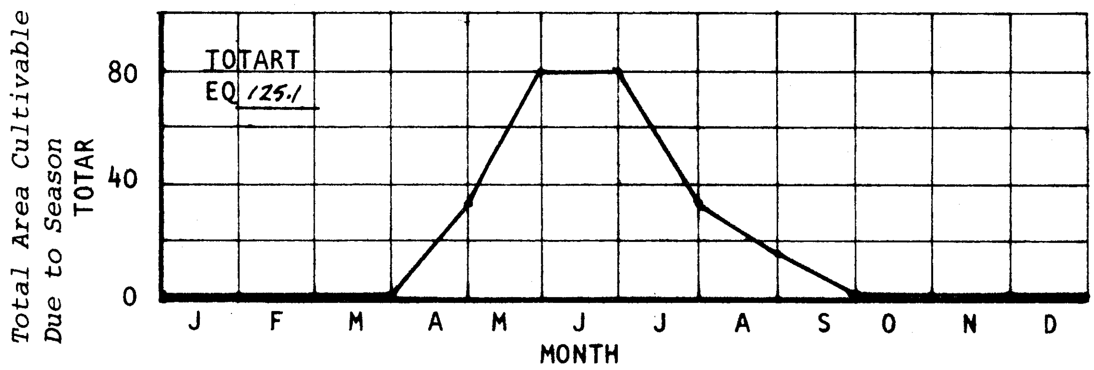
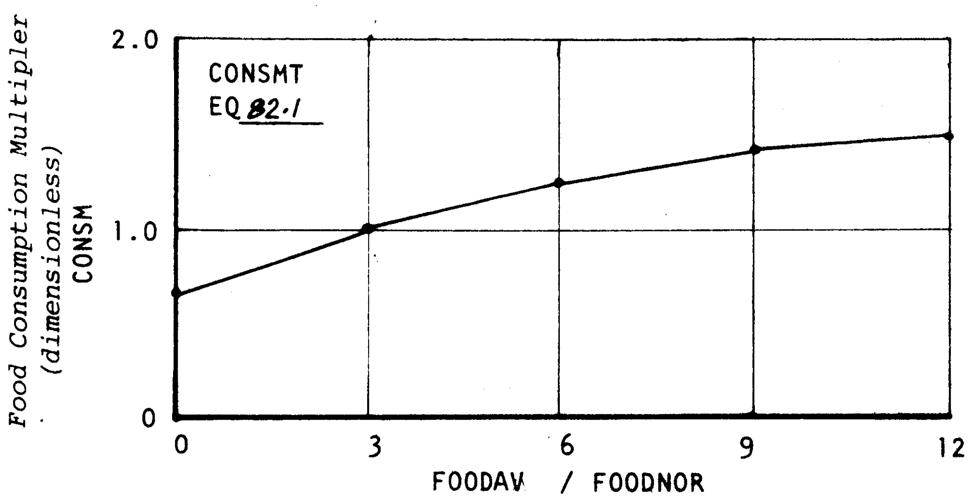


Fig. 26



Ratio of Available Food to Normal Monthly Food Supply

Fig. 27

months, on the average (including field preparation, etc), the amount of area coming out of cultivation AROUT was modelled as a sixth order delay of ARIN, with an overall delay of three months (9, 19). The area removed from cultivation AROUT is returned to the pool of uncultivated land ANIC and is again available for planting, as long as weather and other conditions permit. As land is put into cultivation ARIN, ANIC is decreased.

The major factor in establishing the area to be cultivated comes from outside the area subsector. The total desired area ARDES is determined at yearly intervals and represents the estimated total acreage which must be planted over the following year to achieve a desired yield. ARDES is based on averaged values of the previous year's expenses AVPM and crop yields YLDSM, as well as the normal food consumption FOODNOR and animal feed consumption ACONS. The desired reserve values for both food FOODRES and cash DOLRES are also entered into the computation. At yearly intervals ARDES is thus the sum of all expenses, consumptions, and reserves, expressed in kilocalories, divided by the average crop yield per acre. Between yearly computations the desired area ARDES is reduced during each month by the amount of land put into cultivation ARIN (20).

Animals

This model assumes the animals to be dairy cows since they produce a useful protein which can be consumed in many different ways (21). Their number NOAN depends on the amount invested CIAP in both the animals, at $300 a head, and in the necessary land for pasture and haying. For New England it is realistic to provide for two acres per cow, at an average cost of $200 per acre. The total investment required per animal DPA, here taken as $1400, also includes $700 for the investment in haying equipment and shelter for the animals. The labor necessary to take care of dairy cows HPA is estimated at 8 hours per month per animal, including haying and milking (22). Although the model does not explicitly include hay in the food production and consumption equations, haying labor is included in HPA. Since the required hayfield area is part of the investment CIAP, hay is taken care of implicitly (a dairy cow will eat about the equivalent of 6 tons of hay per year; this is about the average yield from two acres). Animal feed consumption can go as high as 5700 pounds per animal per year for intensive dairying, but it is assumed that this community makes high quality hay and does not try to force the maximum possible yield; animal feed consumption UAC is taken as 360,000 kcal/animal months which is about 200 lbs of grain per month. Overall consumption ACONS is the number of cows NOAN times UAC. The yield of food from animals ANYLD is based on a unit yield UAY of 220,000 kcal/animal-month. THis isthe equivalent of a yearly average of 3 gallons per day per cow (a bit less than 3.7 gal/day for a lactation period of 300 days). While this may seem slightly low, it does reflect the presence of calves and heifers in the herd.

Food

Food is produced from both animals and crops in the community. Animal yields are assumed to be relatively stable throughout the year, while crop yields vary according to season and according to the amount of labor, fuel, and fertilzier employed. The amount of food available FOODAV at any point in time is determined by the amount available in the preceding computation interval plus the sum of crop yield YLDR and animal yield ANYLD less food soncumption CONSR and food sales SALESR.

The normal rate of food consumption by people FOODNOR depends on the number of people in the community NOPERS and the normal individual consumption CONSNOR; CONSNOR is 90,000 kcal per month (3000 kcal/day) (23). The actual amount of food consumed CONSI depends not only on FOODNOR, but can be increased or decreased by a consumption multiplier CONSM, and is limited to the amount of food available FOODAV.

CONSM relates the rate of consumption to the ratio of available food to the normal rate of consumption (Fig 28). It is assumed that the residents of the community are willing to tighten their belts a bit if necessary to stretch out a dwindling food supply; thus whenever FOODAV is less than three times the normal consumption FOODNOR, CONSM will decrease food consumption. The consumption multiplier CONSM has a lower limit of 2/3 of normal consumption when there is no food left. Before this point is reached, however, food is purchased to bring the diet up to at least 75% of normal. If the food supply FOODAV is greater than three months of normal consumption, CONSM gradually increases CONSI to a maximum of 1.5 times the normal diet.

Although it is assumed that the community can produce nearly all of its own food, there are some items, such as certain fruits, spices, etc, which are infeasible or impossible to produce in the climate of New England. Therefore, the model assumes that 10% of the basic human diet FOODNOR will be purchased. Added to this are food purchases necessary to supplement on-site production whenever FOODAV drops below 75% of the desired consumption rate; this total is known as the monthly food purchases PURF. The animals take second priority to human inhabitants of the community in consumption of locally produced food. Thus animal feed must be purchased PURAN whenever the consumption from available food supply ACONSI is less than the necessary consumption ACONS.

Sales are made from the supply of food only when the amount available is greater than both animal and human consumption, as well as the desired reserve supply of food FOODRES. FOODRES is determined by the normal consumption FOODNOR times the number of months desired reserve RES, which must be supplied by the user. This limitation on food sales SALESR is the only mechanism for maintaining the reserve supply of food, since consumption increases when more food is available.

AGRICULTURAL SECTOR

FOOD

```
FOODAV.K=FOODAV.J+DT*(YLDR.JK+ANYLD-CONSR.JK-          79, L
  SALESR.JK)
FOODAV=FA                                              79.2, N
FA=1080000                                             79.3, C
    FOODAV  - FOOD AVAILABLE (KCAL) <79>
    YLDR    - CROP YIELD (KCAL/MO) <89>
    ANYLD   - FOOD FROM ANIMALS (KCAL/MO) <87>
    CONSR   - FOOD CONSUMPTION (KCAL/MO) <80>
    SALESR  - FOOD SALES <86>

CONSR.KL=CONSI.K+ACONSI.K                              80, R
CONSI.K=MIN(FOODAV.K/DT,FOODNOR*CONSM.K)               80.2, A
FOODNOR=NOPERS*CONSNOR                                 80.3, N
NOPERS=100 PEOPLE                                      80.4, C
CONSNOR=90000 KCAL/PERS-MO                             80.5, C
    CONSR   - FOOD CONSUMPTION (KCAL/MO) <80>
    CONSI   - HUMAN CONSUMPTION <80.2>
    ACONSI  - ANIMAL CONS FROM AV FOOD <83>
    FOODAV  - FOOD AVAILABLE (KCAL) <79>
    FOODNOR- NORMAL FOOD CONSUMPTION (KCAL/MO) <80.3>
    CONSM   - CONSUMPTION MULTIPLIER <82>
    CONSNOR- UNIT FOOD CONSUMPTION <80.5>

CONSM.K=TABHL(CONSMT,FOODAV.K/FOODNOR,0,12,3)          82, A
CONSMT=0.667/1/1.1/1.4/1.5                             82.1, T
    CONSM   - CONSUMPTION MULTIPLIER <82>
    FOODAV  - FOOD AVAILABLE (KCAL) <79>
    FOODNOR- NORMAL FOOD CONSUMPTION (KCAL/MO) <80.3>

ACONSI.K=MIN((FOODAV.K/DT)-CONSI.K,ACONS)              83, A
ACONS=NOAN*UAC                                         83.1, N
UAC=360000 KCAL/AN-MO                                  83.2, C
PURAN.K=ACONS-ACONSI.K                                 83.3, A
    ACONSI  - ANIMAL CONS FROM AV FOOD <83>
    FOODAV  - FOOD AVAILABLE (KCAL) <79>
    CONSI   - HUMAN CONSUMPTION <80.2>
    NOAN    - NUMBER OF ANIMALS <87.2>
    PURAN   - FEED PURCHASED (KCAL/MO) <83.3>

PURF.K=FIFGE(0,FOODNOR*0.75-FOODAV.K/DT,FOODAV.K/      84, A
  DT,FOODNOR*0.75)+(.1*FOODNOR)
    PURF    - FOOD PURCHASED (KCAL/MO) <84>
    FOODNOR- NORMAL FOOD CONSUMPTION (KCAL/MO) <80.3>
    FOODAV  - FOOD AVAILABLE (KCAL) <79>
```

```
SALESR.KL=MAX(0,FOODAV.K-FOODRES-CONSI.K*DT-            86, R
  ACONSI.K*DT)
FOODRES=FOODNOR*RES                                     86.1, N
RES=12 MONTHS                                           86.2, C
TCONS.K=CONSI.K+PURF.K                                  86.5, S
    SALESR - FOOD SALES <86>
    FOODAV - FOOD AVAILABLE (KCAL) <79>
    FOODRES- FOOD RESERVE (KCAL) <86.1>
    CONSI  - HUMAN CONSUMPTION <80.2>
    ACONSI - ANIMAL CONS FROM AV FOOD <83>
    FOODNOR- NORMAL FOOD CONSUMPTION (KCAL/MO) <80.3>
    TCONS  - TOTAL HUMAN CONSUMPTION (KCAL/MO) <86.5>
    PURF   - FOOD PURCHASED (KCAL/MO) <84>
```

YIELD - ANIMALS

```
ANYLD=NOAN*UAY                                          87, N
UAY=220000 KCAL/AN-MO                                   87.1, C
NOAN=CIAP/DPA                                           87.2, N
DPA=1400 $/ANIMAL                                       87.3, C
CIAP=22400 $                                            87.4, C
LABAN=NOAN*HPA                                          87.5, N
HPA=8 HRS/AN-MO                                         87.6, C
    ANYLD  - FOOD FROM ANIMALS (KCAL/MO) <87>
    NOAN   - NUMBER OF ANIMALS <87.2>
    CIAP   - INVESTMENT IN ANIMALS AND PASTURE <87.4>
    LABAN  - LABOR REQUIRED FOR ANIMAL CARE  (HRS/MO)
               <87.5>
```

YIELD - CROPS

```
YLDR.KL=(YLB.K+YFL.K)*YFM.K                             89, R
YLDR=200000                                             89.1, N
YLB.K=DLINF3(YLB1.K,1.5)                                89.5, A
YFL.K=DLINF3(YFL1.K,1.5)                                89.6, A
YFM.K=TABHL(YFMT,YFM2.K,0,12000,1000)                   89.7, A
YFMT=1/3.25/4.7/5.6/6.2/6.7/7.1/7.5/7.75/8.1/8.35/      89.8, T
  8.6/8.75
    YLDR   - CROP YIELD (KCAL/MO) <89>
    YLB    - CROP YIELD FROM LABOR <89.5>
    YFL    - YIELD FROM FUEL <89.6>
    YFM    - YIELD MULT FROM FERTILIZER <89.7>
```

AGRICULTURAL LABOR

```
YLB1.K=DLINF3(LABR.JK*KCALH*10,1.5)                     93, A
KCALH=175 KCAL/HR                                       93.1, C
    LABR   - AGRICUITURAL LABOR (HRS/MO) <94>
    KCALH  - USEFUL ENERGY OF LABOR <93.1>
```

```
LABR.KL=LABAG.K                                              94, R
LABAG.K=MIN(LAVAG.K,((LABNOR*ARI.K)+(ALABN*AREA.K))          94.2, A
  *LAM.K*LFM.K)
LAVAG.K=LABAV-LABMD.K-LABAN                                  94.3, A
LABNOR=26 HRS/ACRE                                           94.4, C
ALABN=8                                                      94.5, C
    LABR    - AGRICULTURAL LABOR (HRS/MO) <94>
    LAVAG   - LABOR AVAILABLE FOR AGRICULTURE (HRS/MO)
                <94.3>
    AREA    - AREA IN CULTIVATION <124>
    LAM     - LABOR MULTIPLIER FROM AREA <97>
    LFM     - LABOR MULTIPLIER FROM FUEL USE <99>
    LABAV   - TOTAL LABOR AVAILABLE (HRS/MO) <137.1>
    LABMD   - DIGESTER LABOR <76>
    LABAN   - LABOR REQUIRED FOR ANIMAL CARE  (HRS/MO)
                <87.5>

LAM.K=FIFGE(2.5,ALAM.K,GHA,TOTAR.K)                          97, A
ALAM.K=TABHL(ALAMT,((ARI.K/DT)*(12-MONTH.K))/                97.2, A
  (ARDES.K+1E-6),0,1,0.2)
ALAMT=5/3/2/1.4/1.2/1                                        97.3, T
    LAM     - LABOR MULTIPLIER FROM AREA <97>
    GHA     - GREENHOUSE AREA (ACRES) <125.2>
    TOTAR   - SEASONAL AREA LIMITATIONS <125>
    ARDES   - TOTAL AREA PROJECTED FOR YEAR <117>

LFM.K=TABHL(LFMT,GPA.K,0,10,2.5)                             99, A
LFMT=11/6.7/4/2.2/1                                          99.1, T
    LFM     - LABOR MULTIPLIER FROM FUEL USE <99>
    GPA     - UNIT FUEL USE (GAL/ACRE) <111.3>

                    FERTILIZER INPUTS

YFM2.K=DLINF3(YFM1.K,1.5)                                    100, A
YFM1.K=DLINF3(FERUR.JK/(ARIN.JK+1E-2),1.5)                   100.2, A
    FERUR   - FERTILIZER USE FOR CROPS <102>
    ARIN    - AREA PUT INTO CULTIVATION (AC/MO) <122>

FERUR.KL=MIN(FERUD.K,(FERAV.K/DT)-FERHF.K)                   102, R
FERUR=0                                                      102.1, N
    FERUR   - FERTILIZER USE FOR CROPS <102>
    FERUD   - FERTILIZER USE DESIRED (LBS/MO) <103.3>
    FERAV   - TOTAL FERTILIZER USE (LBS/MO) <50>
    FERHF   - FERTILIZER USED ON HAYFIELDS <51>

FERURD.KL=FERUD.K                                            103, R
FERURD=12000                                                 103.1, N
FERUD.K=FERNOR*FERMOD.K*ARI.K                                103.3, A
FERNOR=4000 LB/ACRE                                          103.4, C
    FERUD   - FERTILIZER USE DESIRED (LBS/MO) <103.3>
    FERMOD - FERTILIZER USE MODIFIER <105>
```

```
FERMOD.K=MIN(FERA.K*FERF.K,3)                              105, A
FERA.K=FIFGE(3,1,GHA,TOTAR.K)                              105.2, A
FERF.K=TABHL(FERFT,FERUR.JK/(FERURD.JK+1E-6),0,1,          105.3, A
  .25)
FERFT=3/2/1.5/1.2/1                                        105.5, T
    FERMOD - FERTILIZER USE MODIFIER <105>
    FERA   - MODIFIER FROM AREA LIMITATIONS <105.2>
    FERF   - MODIFIER FROM PREVIOUS APPLICATIONS <105.3>
    GHA    - GREENHOUSE AREA. (ACRES) <125.2>
    TOTAR  - SEASONAL AREA LIMITATIONS <125>
    FERUR  - FERTILIZER USE FOR CROPS <102>

FERPUR.KL=FERURD.JK-FERUR.JK                               108, R
    FERPUR - FERTILIZER PURCHASES (LBS/MO) <108>
    FERUR  - FERTILIZER USE FOR CROPS <102>
```

FUEL INPUTS

```
YFL1.K=DLINF3(GUFR.JK*EFM.K*KCG,1.5)                       109, A
GUFR.KL=FUS.K+FPUR.K                                       109.2, R
KCG=32000 KCAL/GAL                                         109.3, C
    GUFR   - GASOLINE USED <109.2>
    EFM    - FUEL EFFECTIVENESS <111>
    KCG    - ENERGY VALUE OF GASOLINE <109.3>
    FUS    - (GAL/MO) <113>
    FPUR   - FUEL PURCHASES (GAL/MO) <115>

EFM.K=TABXT(EFMT,GPA.K,0,25,5)                             111, A
EFMT=5/3.63/2.63/1.5/1.25/1                                111.1, T
GPA.K=GUFR.JK/(ARIN.JK+1E-2)                               111.3, A
    EFM    - FUEL EFFECTIVENESS <111>
    GPA    - UNIT FUEL USE (GAL/ACRE) <111.3>
    GUFR   - GASOLINE USED <109.2>
    ARIN   - AREA PUT INTO CULTIVATION (AC/MO) <122>

FUS.K=FIFGE(0,MIN(FUNOR*FDM.K*ARI.K,GAF.K),GHA,            113, A
  TOTAR.K)
GAF.K=FIFGE(GUP.K/CFG,0,CIAM,MCIAM)                        113.2, A
CFG=250 CUFT/GAL                                           113.3, C
    FUS    - (GAL/MO) <113>
    FDM    - FUEL USE MODIFIER FROM CASH AVAILAB <116>
    GAF    - GAS AVAILABLE FOR FUEL (GAL EQUI <113.2>
    GHA    - GREENHOUSE AREA (ACRES) <125.2>
    TOTAR  - SEASONAL AREA LIMITATIONS <125>
    GUP    - GAS USE POSSIBLE (CUFT/MO) <67>
    CFG    - BIOGAS-GASOLINE CONVERSION <113.3>
    CIAM   - INVESTMENT IN AGRICULTURAL MACHINERY
               <116.2>
    MCIAM  - MIN INV IN AGRI MACH <116.3>
```

```
FPUR.K=FIFGE(0,FIFGE(MAX((FUNOR*ARI.K)-                    115, A
  SMOOTH(GAF.K,2),0),0,CIAM,MCIAM),GHA,TOTAR.K)
FUNOR=10 GAL/ACRE                                          115.2, C
    FPUR    - FUEL PURCHASES (GAL/MO) <115>
    GAF     - GAS AVAILABLE FOR FUEL (GAL EQUI <113.2>
    CIAM    - INVESTMENT IN AGRICULTURAL MACHINERY
                <116.2>
    MCIAM   - MIN INV IN AGRI MACH <116.3>
    GHA     - GREENHOUSE AREA (ACRES) <125.2>
    TOTAR   - SEASONAL AREA LIMITATIONS <125>

FDM.K=TABHL(FDMT,DR.K,-12,12,6)                            116, A
FDMT=2/1.93/1.8/1.6/1                                      116.1, T
CIAM=3000 $                                                116.2, C
MCIAM=3000 $                                               116.3, C
    FDM     - FUEL USE MODIFIER FROM CASH AVAILAB <116>
    DR      - EXPENSE RATIO <131.3>
    CIAM    - INVESTMENT IN AGRICULTURAL MACHINERY
                <116.2>
    MCIAM   - MIN INV IN AGRI MACH <116.3>

                CROP AREA

ARDES.K=FIFGE((((FOODNOR+ACONS+(AVPM.J/DCAL))*12)+         117, L
  FOODRES+(DOLRES.J/DCAL))/YLDSM.J,ARDES.J-DT*
  ARIN.JK,0.25,MONTH.J-0.2)
ARDES=ARD                                                  117.3, N
ARD=1                                                      117.4, C
    ARDES   - TOTAL AREA PROJECTED FOR YEAR <117>
    FOODNOR- NORMAL FOOD CONSUMPTION (KCAL/MO) <80.3>
    AVPM    - SMOOTHED MONTHLY PAYMENTS <133>
    DCAL    - UNIT CROP VALUE <127.1>
    FOODRES- FOOD RESERVE (KCAL) <86.1>
    DOLRES  - RESERVE CASH <134>
    ARIN    - AREA PUT INTO CULTIVATION (AC/MO) <122>

YLDSM.K=SMOOTH(YLDR.JK,APER)                               118, A
YLDSM=24000000                                             118.1, N
    YLDR    - CROP YIELD (KCAL/MO) <89>
    APER    - SMOOTHING PERIOD <133.1>

ANIC.K=ANIC.J+DT*(AROUT.JK-ARIN.JK)                        119, L
ANIC=TCA                                                   119.1, N
TCA=CIA/DPAC                                               119.2, N
DPAC=300 $/ACRE                                            119.3, C
CIA=24000 $                                                119.4, C
    ANIC    - AREA NOT IN CULTIVATION (ACRES) <119>
    AROUT   - AREA REMOVED FROM CULTIVATION (AC/MO) <120>
    ARIN    - AREA PUT INTO CULTIVATION (AC/MO) <122>
    TCA     - TOTAL CULTIVABLE AREA (ACRES) <119.2>
    CIA     - INVESTMENT IN CROPLAND <119.4>
    DPAC    - UNIT LAND COST <119.3>
```

```
AROUT.KL=DELAY3(AROUT1.JK,1.5)                              120, R
AROUT1.KL=DELAY3(ARIN.JK,1.5)                               120.2, R
AROUT1=0                                                    120.3, N
    AROUT  - AREA REMOVED FROM CULTIVATION (AC/MO) <120>
    ARIN   - AREA PUT INTO CULTIVATION (AC/MO) <122>

ARIN.KL=ARI.K                                               122, R
ARI.K=MIN(MIN(ANIC.K,MAX(TOTAR.K-AREA.K,0)),                122.2, A
  ARDES.K)
    ARIN   - AREA PUT INTO CULTIVATION (AC/MO) <122>
    ANIC   - AREA NOT IN CULTIVATION (ACRES) <119>
    TOTAR  - SEASONAL AREA LIMITATIONS <125>
    AREA   - AREA IN CULTIVATION <124>
    ARDES  - TOTAL AREA PROJECTED FOR YEAR <117>

AREA.K=TCA-ANIC.K                                           124, A
    AREA   - AREA IN CULTIVATION <124>
    TCA    - TOTAL CULTIVABLE AREA (ACRES) <119.2>
    ANIC   - AREA NOT IN CULTIVATION (ACRES) <119>

TOTAR.K=TABHL(TOTART,MONTH.K,0,12,1)                        125, A
TOTART=.25/.25/.25/.25/32/80/80/32/16/.25/.25/.25/          125.1, T
  .25 ACRES
GHA=CIGA/DAGH                                               125.2, N
DAGH=100000 $/ACRE                                          125.3, C
CIGA=25000 $                                                125.4, C
    TOTAR  - SEASONAL AREA LIMITATIONS <125>
    GHA    - GREENHOUSE AREA (ACRES) <125.2>
    CIGA   - INVESTMENT IN GREENHOUSE <125.4>
    DAGH   - UNIT GREENHOUSE COST <125.3>
```

AGRICULTURAL SECTOR NOTES

(For complete citations, please refer to Bibliography)

1 Heichel.

2 Pimental *et al.*

3 Steinhart.

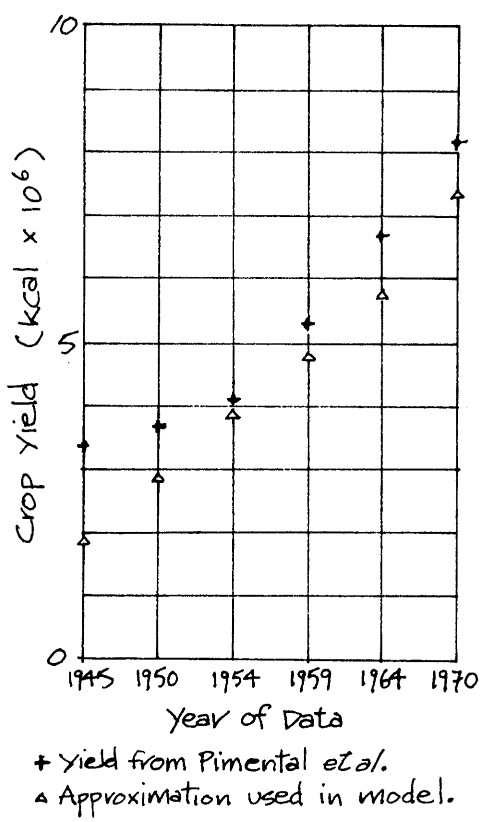
4 Heichel; Pimental *et al;* Steinhart; Leach; Makhijani and Poole; Meadows; Merrill, "Energy and Agriculture."

5 Pimental *et al,* p 446.

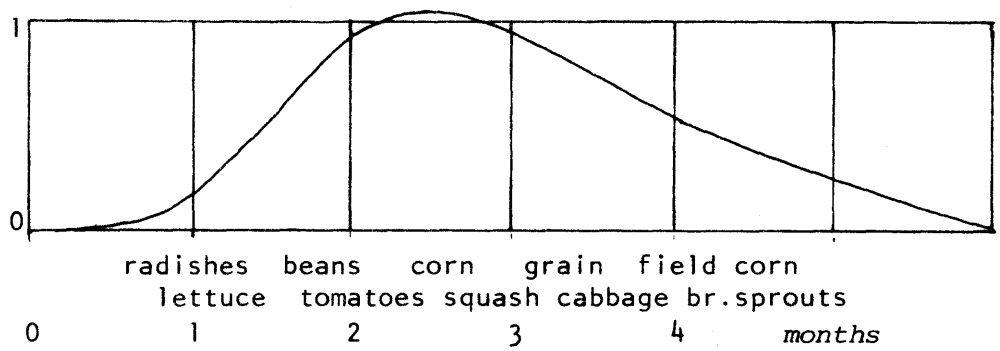
6 Meadows, *et al,* pp 297-8, 305.

7 Pimental *et al,* p 445.

8 The accompanying table illustrates the results of using my approximations on fertilizer, fuel, and labor data from Pimental *et al,* p 445.



9 The output rates for both first and third order DYNAMO delays did not seem appropriate for modelling agricultural yields, since both these delays have substantial output very quickly after the initial input, whereas in reality there is a period of time after planting with no yield at all. A sixth order delay (in actuality, two nested third order delays) has an output that more closely resembles real life, especially with a mixed cropping system.



Yield Rate for Unit Input, 6th Order Delay, and 3 Month Delay Time

from Forrester, p. 92.

10 Heichel, pp 13, 25.

11 Leach, p 11.

12 There may be some reason to believe that there is an effective limit to the amount of labor which can usefully be applied to a given area, and that diminishing returns will result from increasing labor beyond that point. The amount of energy input in the New Guinea example, however, represents about 3200 hours per acre, while the present model structure limits labor inputs to 2750 hours per acre at the extreme, so it is probably below the range where the effect of diminishing returns will begin to occur.

13 Heichel, p 8, assigns an energy value of 32,000 kcal to one gallon of gasoline, while Pimental *et al*, p 445, use 36,225. I have adopted the former figure because 250 cubic feet of biogas with an average Btu content of 500/cu ft is equivalent to 31,500 kcal.

14 The amount of fuel required to plow one acre would be about six times the amount of fuel required to spray one acre, but it would take much more than six times the human labor to work the ground than it would to spray.

15 The maximum factor of 11 times the normal labor of 50 hours/acre was chosen to give about the same yield as 10 gallons of gasoline plus 50 hours of labor per acre.

16 Fry and Merrill, p 23.

17 Both Meadows *et al*, p 297, and Pimental *et al*, p 446, present curves for the relationship between fertilizer application per unit area and resulting yields. Fuel and labor inputs are probably not held constant, however. I have adapted the curve of Meadows *et al* in Figure 24; data from Pimental *et al* plotted against this curve fit fairly well.

18 Pimental *et al*, p 446, state that 10 tons of manure is about equivalent to 112 pounds of nitrogen fertilizer. If the ratio of digested sludge fertilizer to dry waste is about 1 and the ratio of dry waste to wet manure about .2, then two tons of digested waste would be the equivalent of 10 tons of raw manure. According to Fry and Merrill, p 25, the nitrogen content of digested material ranges from 1.4 - 4.9%, which comes to about 56 - 196 pounds in two tons. This is a reasonable correlation with the statements of Pimental *et al*. I have specified two tons of digested material per acre as the normal fertilzier application FERNOR in order to maintain soil fertility. For the length of time that this mdoel simulates, a few years at most, it is not important that the model has no mechanism for simulating a decline in soil fertility if digested fertilizer is not used consistently; this would become necessary for realistic model runs of greater than 10 years or so if fertilizer use was also able to drop below the two tons per acre specified.

19 The large order delay was chosen because crop land does not generally come out of cultivation immediately after planting; although even the sixth order delay will cause some area to come out of cultivation soon after it is put in, the effect is minimized.

20 The particular structure of the equation for ARDES causes DYNAMO to flag it as "UNUSUAL FORMAT OF LEVEL EQUATION FOR ARDES," and list it as an error, but the model is not prevented from running. There is probably a better way to write the equation for this two level structure of ARDES.

21 Dairy products include milk, butter, cream, yogurt, cheeses, and if one wants the goose as well, meat.

22 All figures for animal food consumption, yields, and labor necessary to maintain animals are based on data provided by Benson, pp 72-74 and on personal experience. It is possible to increase the yield of milk with increased levels of feeding, but most cows which experience such a regime do not last more than a few years in a dairy; a well-tended family cow can theoretically give milk for 10-20 years.

23 Consumption is described in terms of calories because it is easier to relate them to energy than it is for protein, vitamins, or minerals. One Food calorie has the equivalent of 1000 calories of energy content.

d

Building Energy Flow Sector

BUILDING ENERGY SECTOR

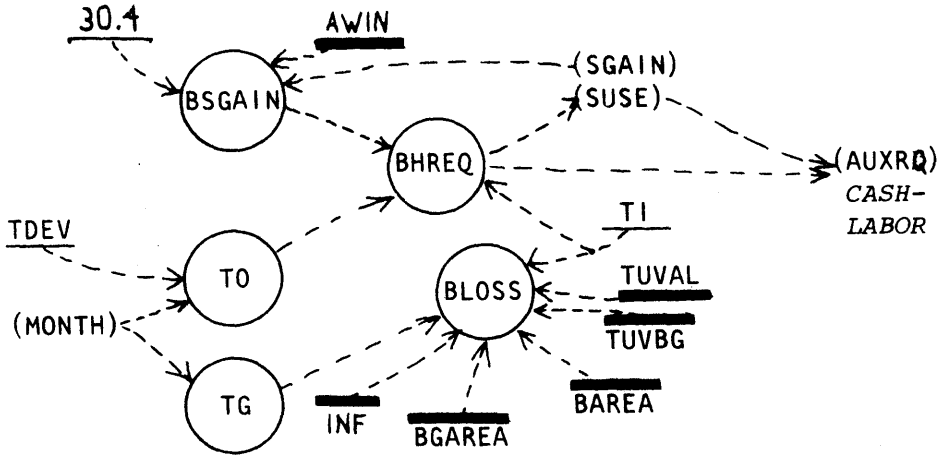
The building energy sector serves to bring together the community's energy production and its energy requirements. Although only one of the various energy requirements, space heating, is directly related to the properties of the building structure, all uses of energy in the community (outside of the agricultural sector) are grouped here. The major uses treated include space and water heating, electricity demands, and cooking. Primary energy sources are solar energy, wind energy, and wood, while alternate sources possible include gas produced in the digester sector and purchased supplements. One source which can produce a surplus of energy above needs is the wind generator; a surplus ultimately decreases the total community expenditures. Since most of the energy-use relationships are independent of one another, the flow diagram for the building energy sector is fragmented; Figures 28-32 illustrate the various flows.

Space Heating

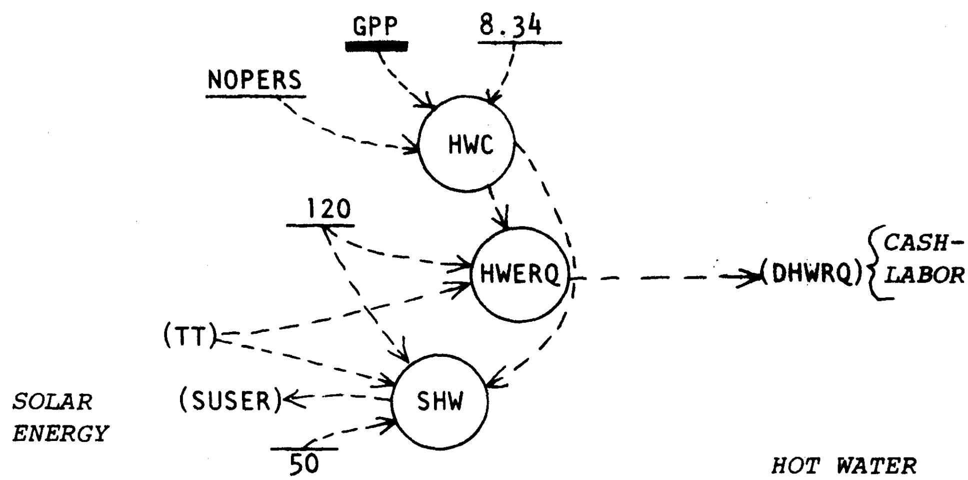
Solar energy is assumed to be the major source of energy for space heating (Fig. 28). If insufficient solar energy is available, either from storage or current collection, auxiliary fuel must be purchased. The model compares building heat requirements BHREQ with the net amount of solar energy available NSAV during the computation period in order to determine the amount of auxiliary fuel purchased AUXRQ. The building heat requirements are a function of building heat losses BLOSS and solar gains through south facing windows BSGAIN.

Because of the complexity of the parameters associated with building construction, it was felt that it would be too misleading and inaccurate to attempt to handle the effects of investments in buildings like the other investments in the model, i.e., investments generating particular sizes or capacities of components. For the building sector this data must be supplied by the user of the model; the total building cost CIBLDG is entered only as input to the cash-labor sector. The modeller must also provide values for the surface area of the buildings both above ground BAREA and below ground BGAREA. For the heat loss calculations net values of building thermal conductivity must also be entered, again for both above TUVAL and below ground TUVBG portions of the building. To determine solar gains, the area of south facing windows AWIN must be provided. While there may be some benefit to incorporating a relationship between additional investments and improved energy conservation, it was felt that this field was also too complex to allow simple modelling, especially considering the multitude of ways in which energy conservation could be achieved--extra insulation, storm windows, and extra tight construction are just a few of the obvious ways. Since there are so many possibilities open to the designer of a building the model must be capable of allowing as many of these as possible. If the modeller precalculates this information many more types of building sizes, shapes, densities, materials, and construction methods can be evaluated than would be possible with an investment-generated parameter.

Building heat losses are calculated using the basic heat loss equation $Q = U \times A \times (T_i - T_o)$ (translated into the appropriate DYNAMO equation). The losses BLOSS are calculated for both above and below ground portions of the building; this flexibility was included in the model to allow



Space Heating
Fig. 28



Hot Water
Fig. 29

the evaluation of the moderating effect of the earth's heat (1). The overall thermal conductivity of both parts of the building should be entered by the user from calculations made for the specific design; if it can be assumed that the community is highly conservation minded the U value below ground TUVBG would be at least .05 while the overall U value above ground TUVAL would approach .1 (2). These values will be used by the model unless they are changed by the user. The areas provided for both above ground BAREA and below ground BGAREA are also used in determining heat losses.

The inside temperature TIN is another parameter which can be altered to suit the designer's intent; if no other value is supplied the model will use 65°F in its calculations. Outside temperature TO is derived from tabular input which should be provided for the site in question TOUT (Fig 8, 3); the values in this table, mean monthly temperatures, are used with the DYNAMO normal distribution function to generate randomized average temperatures TO. The monthly deviation from the mean TDEV, 8°, was determined from analysis of about 15 years of monthly temperature data for 8 locations in Maine. The value for ground temperature TG must also be provided in a table; as ground temperature is not subject to random variations this value is used directly from the table according to the season (Fig 8, 3).

The final parameter involved in determining heat losses is a factor for heat loss due to air infiltration INFIL. This is another value which must be supplied by the modeller; it should be based on the expected percentage of heat loss due to infiltration. A tight building might lose only 1/3 of its total heat loss from infiltration, so the model uses a multiplier of 1.3 unless it is otherwise specified. To convert these hourly losses to monthly losses, the total hourly losses are multiplied by 730, the average hours in a month.

Once the monthly heat loss BLOSS is calculated, it is compared with the building solar gains BSGAIN to determine the net heat required BHREQ. No heat will be required if the gains are greater than the losses. Also, since internal heat gains from people, lights, and appliances make up for about 5^{o} difference between outside and inside temperatures, if the outside temperature TO is less than 5^{o} below the inside temperature TIN, the model will not call for any heat (4). The amount of heat required BHREQ which can be supplied by the available solar energy NSAV is called solar space heat supplied SSH and is used in the solar-wind sector in the equation for solar energy use SUSER. Any remaining heat requirements must be met by purchased fuel AUXRQ (5).

Water Heating

Useful energy in domestic water heating (Fig 29) is measured somewhat differently from useful energy for space heating. Since domestic hot water is used and must be replenished by water at a lower temperature, any storage temperature greater than the inlet temperature will decrease the amount of energy required to heat the water to a usable temperature. The temperature of the storage tank TT is calculated only for the purpose of determining hot water energy requirements and is measured after space heating needs are deducted from the energy available. This mechanism was intended to simplify the calculations and should not affect the total auxiliary heat required for space and water heating. TT is calculated from the difference between the total solar energy available NSAV and space heating supplied from solar energy SSH, the difference then being divided by the unit thermal capacity of the storage (SCAP x CP). 55^{o} is added to the result of these computations, since this has already been given as the equilibrium temperature of the storage and as the point which is defined as containing zero energy.

Hot water requirements do not vary, but are determined only from the number of inhabitants NOPERS and an average hot water use GPP, which is 300 gallons per person per month in the model (6). The amount of hot water energy available from solar storage SWH depends on the temperature of the storage. The average hot water temperature desired in the model is set at $120^{o}F$; if the tank temperature is greater than 120^{o}, all the hot water requirements can be met from storage. If TT is less than 120^{o}, then auxiliary water heating is required HWERQ.

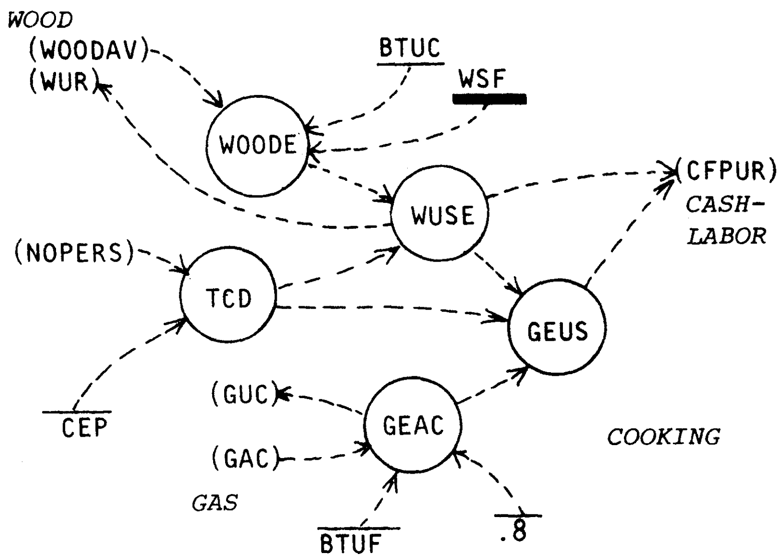
Cooking

It has been suggested that the use of biogas for cooking purposes is not the most economical approach to utilization of this resource, especially if there are other energy demands(7). While the energy required for cooking is of a higher order than that needed for space heating, it is still a relatively low grade of energy when compared to the high grade of chemical energy stored in biogas. In view of these considerations the model was structured to place primary emphasis on wood as a cooking fuel, with gas use possible as a low priority backup

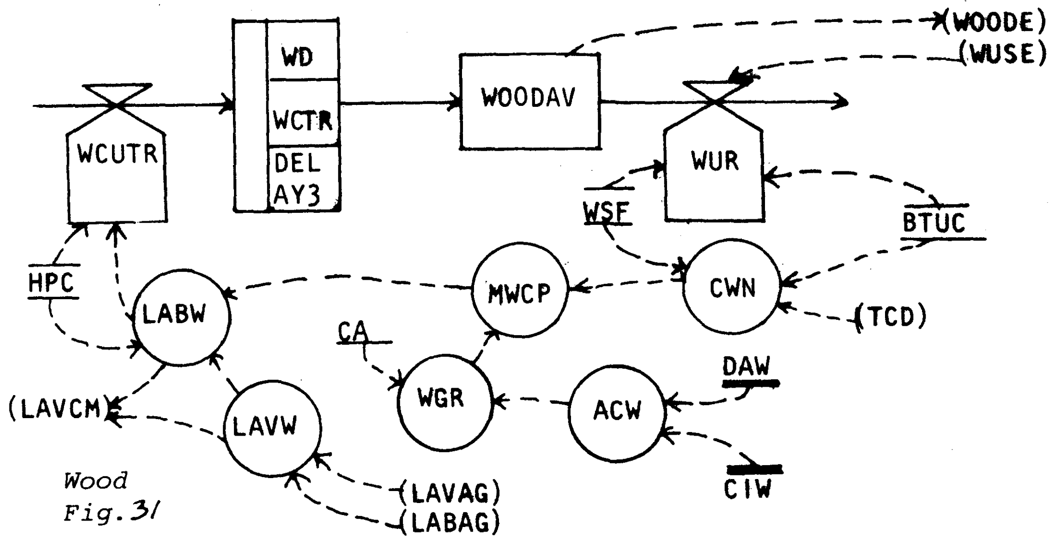
(Figs 30, 31). It is not altogether clear that the vast majority of Americans would want to give up the convenience of having energy available at the turn of a knob, with little forethought necessary, but an already large and increasing number of people in New England do use wood for cooking or heating. In forested regions, like New England, wood is a logical choice of fuel for cooking; it is basically solar energy stored in chemical form.

The total cooking energy demand TCD is constant, depending only on the number of people NOPERS and the useful cooking energy required CEP, which is taken as 292,000 Btu per person per month (8). Total auxiliary cooking fuel purchases CFPUR are determined from the difference between the demand TCD and the sum of energy used from both wood WUSE and gas GEUS. Since wood is the primary source of cooking fuel, its use is limited only by the amount of wood energy available WOODE, the fuel value of the wood BTUC, and the stove efficiency WSF. WOODE is directly related to the amount of wood available WOODAV, which is discussed later in the section on wood. The fuel value of wood BTUC equals 18 million Btu per cord, which was taken to be an average between the wet and dry fuel values of a good hardwood such as oak or maple. The average was used because there is no mechanism in the model for simulating the drying time of wood. Wood stove efficiency is also an average value, 50% (9).

If insufficient wood is available, or if there is no investment in wood as an energy source, gas can be used for cooking; cooking is the lowest priority gas use however. The energy available from the gas GEAC depends



Cooking
Fig. 30



Wood
Fig. 31

on the amount of gas available, the fuel value of the gas BTUF, and stove efficiency. BTUF is taken as 600 Btu per cubic foot of biogas, while the gas stove efficiency is 80%. The amount of gas used in cooking GEUS is the minimum value of either the desired amount of gas use or the amount of gas available.

Wood

A woodlot could be a valuable asset for a community; besides the fuel which could be obtained on a continuous basis from a properly managed woodlot, it would also be suitable for recreation and its beauty could contribute to aesthetic aspects of the community. Properly managed, a woodlot could be expected to produce a greater growth of wood than natural forest.

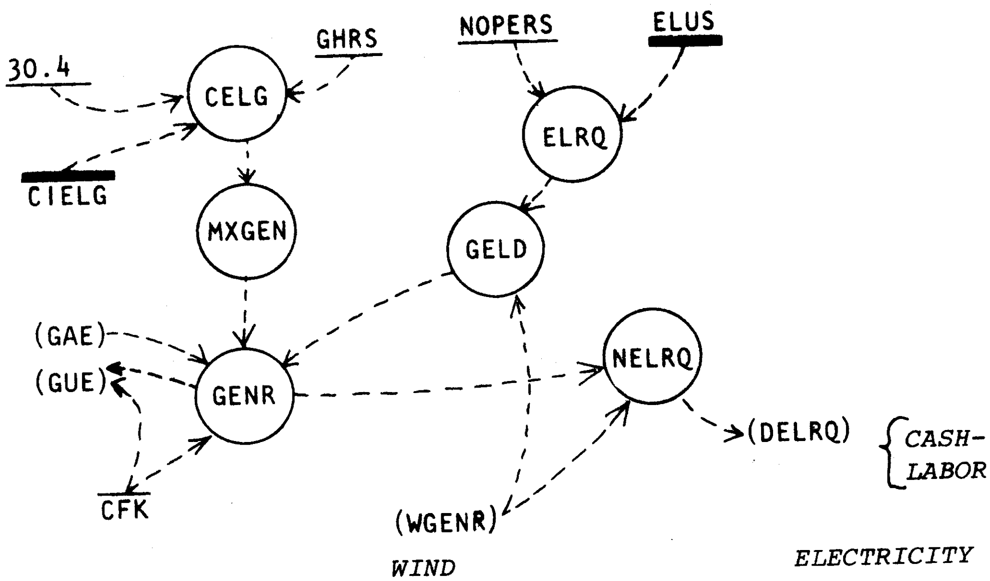
The amount of wood available WOODAV is primarily dependent on the rate of wood use WUR and the rate of wood availability from cutting WCTR. If enough wood were available, WUR would be constant, as would be WCTR if enough labor were always available. The number of cords of wood needed for cooking CWN is the product of the total cooking energy demand TCD, the fuel value of the wood BTUC and the wood stove efficiency WSF; these parameters are described in the previous section on cooking. CWN is then compared to the growth of wood available for cutting WGR to determine the maximum amount of woodcutting possible MWCP. WGR depends on the unit wood growth rate CA, .1 cords/acre-month (10), and the area of the woodlot ACW. ACW is in turn derived from the investment in the woodlot CIW and the cost per acre DAW, which is given a value of $200 per acre for reasonable woodland in northern New England.

The last limiting factor in woodcutting is labor availability; agricultural, digester, and animal labor requirements must be satisfied before woodcutting can take place. If insufficient labor is available to cut all the wood needed, then only as much as is possible is cut. This will result in an eventual need for auxiliary fuel, since at present there is no mechanism in the model which would cause woodcutting to proceed at a rate greater than the desired use rate. It is assumed that it takes 8 hours of labor to prepare one cord of wood HPC; obviously, this would be much greater if no power tools were used. There is also assumed to be an average of one month's delay between the time wood is begun to be cut and the time that it is available for use WD. This delay is representative of the time to cut and trim the trees, haul them out of the woodlot, and cut and split them into usable pieces; it also allows for a limited amount of drying time.

Electricity

Electricity use is fairly straightforward (Fig 32). Two options are available if the community wishes to generate its own electricity; these are wind power and the use of biogas in a generator. Either or both of these options can be evaluated simply by entering values for their respective capital investment parameters, CIWG and CIELG (gas generated electricity, of course, also depends on an investment in a waste digester MDCI). Where wind speeds are too low to justify wind generation of electricity, the ability to generate electricity with gas would be particularly desirable.

The basic amount of electrical consumption in the model, like water consumption, is invariable; the individual consumption of electricity ELUS is estimated at 75 kwh per month (11). The net auxiliary



Electricity
Fig. 32

electrical requirement NELRQ is determined from ELRQ and the amount of electricity available from the wind WGENR and gas GENR (wind generation of electricity is discussed with the solar-wind energy sector).

The amount of electricity which can be obtained from gas GENR depends on the amount of energy in the gas which can be allocated to electrical generation EAG (as agricultural fuel use has priority over other gas uses in this model, it could happen that there would be no gas left for other uses). It is also a function of the generator rating CELG and on the average number of hours which the generator will be used GHRS, here taken as 16 hours per day (12). The generator rating CELG is determined directly from the investment in generator capacity CIELG and the unit generator cost UGC, which is $200/kwe in the model (13).

For a given generator size CELG and number of hours of use GHRS there is a maximum amount of electricity that could be generated MXGEN, if the fuel is available. MXGEN is the product of CELG and GHRS, converted from hourly to monthly data by multiplying with the fraction 730/24 (see Note 4 in the solar-wind energy sector). Actual electrical generation from gas GENR is determined by comparing MXGEN to the amount of energy available in the gas EAG, and the minimum of these is then compared to the amount of electricity desired from gas GELD (14). If the amount of wind generated electricity, WGENR exceeds the basic electrical requirements ELRQ a surplus results. The surplus is sold and the proceeds are deducted from the total monthly expenses. In this case no gas would be used for electrical generation, if this option is available.

BUILDING ENERGY FLOW SECTOR

SPACE HEATING

```
BHREQ.K=MAX(FIFGE(BLOSS.K-BSGAIN.K,0,TIN,TO.K+5),0)  25, A
    BHREQ  - BUILDING HEAT REQD (BTU/MO) <25>
    BLOSS  - BUILDING HEAT LOSS,  BTU/MONTH <27>
    BSGAIN - BUILDING SOLAR GAIN (BTU/MO) <26>
    TIN    - INSIDE AIR TEMPERATURE <27.6>
    TO     - AVERAGE OUTSIDE TEMPERATURE <28>

BSGAIN.K=SGAIN.K*AWIN*AT*730/24                      26, A
AWIN=0 SQFT                                          26.1, C
AT=.8                                                26.2, C
CIBLDG=0 $                                           26.3, C
    BSGAIN - BUILDING SOLAR GAIN (BTU/MO) <26>
    SGAIN  - DAILY INCIDENCE ON S WALL (BTU/SQFT) <6>
    AWIN   - AREA OF SOUTH WINDOWS <26.1>
    AT     - AVERAGE ALPHA-TAU PRODUCT <26.2>
    CIBLDG - INVESTMENT IN BUILDINGS <26.3>

BLOSS.K=(TUVAL*BAREA*(TIN-TO.K)+TUVBG*BGAREA*(TIN-   27, A
  TG.K))*INFIL*730
TUVAL=.15 BTU/HR-SQFT-DEG(F)                         27.2, C
TUVBG=.07 BTU/HR-                                    27.3, C
BAREA=0 SQFT                                         27.4, C
BGAREA=0 SQFT                                        27.5, C
TIN=65 DEG(F)                                        27.6, C
INFIL=1.3                                            27.7, C
    BLOSS  - BUILDING HEAT LOSS,  BTU/MONTH <27>
    TUVAL  - NET U-VALUE FOR BUILDING, INCL WINDOWS
               <27.2>
    BAREA  - SURFACE AREA ABOVE GROUND <27.4>
    TIN    - INSIDE AIR TEMPERATURE <27.6>
    TO     - AVERAGE OUTSIDE TEMPERATURE <28>
    TUVBG  - NET U-VALUE FOR BELOW GROUND PORTION OF
               BLDG <27.3>
    BGAREA - SURFACE AREA BELOW GROUND <27.5>
    TG     - GROUND TEMPERATURE <30>
    INFIL  - INFILTRATION FACTOR <27.7>

AUXRQ.K=BHREQ.K-SSH.K                                31, A
    AUXRQ  - AUXILIARY HEAT REQD (BTU/MO) <31>
    BHREQ  - BUILDING HEAT REQD (BTU/MO) <25>
    SSH    - SOLAR SPACE HEATING (BTU/MO) <11>
```

TEMPERATURES

```
TO.K=NORMRN(TOU.K,TDEV)                                        28, A
TOU.K=TABLE(TOUT,MONTH.K,0,12,0.5)                             28.1, A
TOUT=20/18/19/21/27/31/36/41/48/55/59/62/67/70/70/             28.2, T
  66/63/60/53/47/41/36/29/23/20 DEG(F)
TDEV=8 DEG(F)                                                  28.4, C
    TO      - AVERAGE OUTSIDE TEMPERATURE <28>
    TOU     - MONTHLY MEAN OUTSIDE TEMPERATURE <28.1>

TG.K=TABLE(TGT,MONTH.K,0,12,0.5)                               30, A
TGT=38.5/37/36/35/34/34/35/38/42.5/47.5/53/58/62/              30.1, T
  63.5/64.5/64/63/62/60.5/58/54/50/47/43.5/40.5
  DEG(F)
    TG      - GROUND TEMPERATURE <30>
```

HOT WATER

```
SHW.K=MIN((MIN(120,TT.K)-IWT)*HWC,NSAV.K-SSH.K)        32, A
IWT=50 DEG(F)                                           32.1, C
HWC=NOPERS*GPP*CP                                       32.2, N
GPP=300 GAL/PERS-MO                                     32.3, C
    SHW     - HW FROM STORAGE <32>
    TT      - TANK TEMP AFTER SPACE HEAT <19>
    IWT     - INLET WATER TEMP <32.1>
    HWC     - HW THERMAL CAPY PER DEG(F) HEATING REQD
                <32.2>
    NSAV    - NET SOLAR AVAILABLE FOR SPACE HEATING (BTU/
                MO) <12>
    SSH     - SOLAR SPACE HEATING (BTU/MO) <11>

HWERQ.K=MAX(HWC*(120-TT.K),0)                           33, A
    HWERQ   - HW AUXILIARY HEAT REQD (BTU/MO) <33>
    HWC     - HW THERMAL CAPY PER DEG(F) HEATING REQD
                <32.2>
    TT      - TANK TEMP AFTER SPACE HEAT <19>
```

ELECTRICITY

```
NELRQ.K=ELRQ-WGENR.K-GENR.K                             34, A
ELRQ=NOPERS*ELUS                                        34.1, N
ELUS=75 KWH/PERS-MO                                     34.2, C
    NELRQ   - NET ELEC PURCHASES (SALES) (KWH/MO) <34>
    ELRQ    - ELECTRICITY REQD (KWH/MO) <34.1>
    WGENR   - ELECTRICITY GENERATED, KWH/MO <24>
    GENR    - ELECT FROM BIOGAS (KWH/MO) <35>

GENR.K=MIN(MIN(EAG.K,MXGEN),GELD.K)                     35, A
MXGEN=CELG*(730/24)*GHRS                                35.1, N
GHRS=16 HRS/DAY                                         35.2, C
CELG=CIELG/UGC                                          35.3, N
UGC=200 $/KWE                                           35.4, C
CIELG=0 $                                               35.5, C
    GENR    - ELECT FROM BIOGAS (KWH/MO) <35>
    EAG     - MAX ELECT POSS FROM GAS <37>
    MXGEN   - MAX GEN POSS  (KWH/MO) <35.1>
    GELD    - ELECTRICITY DESIRED FROM GAS (KWH/MO) <36>
    CELG    - GENERATOR RATING (KWE) <35.3>
    GHRS    - HOURS OF GEN OPERATION <35.2>
    CIELG   - INVESTMENT IN GAS ELECTRICAL GENERATOR
                <35.5>

GELD.K=MAX(ELRQ-WGENR.K,0)                              36, A
    GELD    - ELECTRICITY DESIRED FROM GAS (KWH/MO) <36>
    ELRQ    - ELECTRICITY REQD (KWH/MO) <34.1>
    WGENR   - ELECTRICITY GENERATED, KWH/MO <24>
```

```
EAG.K=(GUP.K-GUF.K)/CFK                                      37, A
CFK=21 CUFT/KWH                                              37.1, C
    EAG     - MAX ELECT POSS FROM GAS <37>
    GUP     - GAS USE POSSIBLE (CUFT/MO) <67>
    GUF     - GAS USED FOR FUEL (CUFT/MO) <62.3>
    CFK     - BIOGAS-ELECTRICITY CONVERSION (25%) <37.1>
```

COOKING

```
CFPUR.K=TCD-WUSE.K-GEUS.K                                    38, A
TCD=NOPERS*CEP                                               38.1, N
CEP=2.92E5 BTU/PERS-MO                                       38.2, C
    CFPUR   - COOKING FUEL PURCHASES (BTU/MO) <38>
    TCD     - TOTAL COOKING ENERGY DEMAND (BTU/MO) <38.1>
    WUSE    - ENERGY FROM WOOD (BTU/MO) <39>
    GEUS    - ENERGY FROM GAS (BTU/MO) <41>

WUSE.K=MIN(WOODE.K,TCD)                                      39, A
WOODE.K=WOODAV.K*BTUC*WSF/DT                                 39.2, A
WSF=.5                                                       39.3, C
BTUC=18E6 BTU/CORD                                           39.4, C
    WUSE    - ENERGY FROM WOOD (BTU/MO) <39>
    WOODE   - WOOD ENERGY AVAILABLE (BTU/MO) <39.2>
    TCD     - TOTAL COOKING ENERGY DEMAND (BTU/MO) <38.1>
    WOODAV  - WOOD AVAILABLE (CORDS) <43>
    WSF     - WOOD STOVE EFFICIENCY <39.3>

GEUS.K=MIN(TCD-WUSE.K,GEAC.K)                                41, A
GEAC.K=((EAG.K*CFK)-GUE.K)*BTUF*.8                           41.2, A
BTUF=600 BTU/CUFT                                            41.3, C
    GEUS    - ENERGY FROM GAS (BTU/MO) <41>
    TCD     - TOTAL COOKING ENERGY DEMAND (BTU/MO) <38.1>
    WUSE    - ENERGY FROM WOOD (BTU/MO) <39>
    GEAC    - GAS ENERGY AVAILABLE (BTU/MO) <41.2>
    EAG     - MAX ELECT POSS FROM GAS <37>
    CFK     - BIOGAS-ELECTRICITY CONVERSION (25%) <37.1>
    GUE     - GAS USED FOR ELECTRICITY (CUFT/MO) <62.4>
```

WOOD ENERGY

```
WOODAV.K=WOODAV.J+DT*(WCTR.JK-WUR.JK)                        43, L
WOODAV=WOOD                                                  43.1, N
WOOD=0                                                       43.2, C
    WOODAV  - WOOD AVAILABLE (CORDS) <43>
    WCTR    - RATE OF WOOD AVAILABILITY (CORDS/MO) <45>
    WUR     - WOOD USE RATE (CORDS/MO) <44>

WUR.KL=WUSE.K/(BTUC*WSF)                                     44, R
    WUR     - WOOD USE RATE (CORDS/MO) <44>
    WUSE    - ENERGY FROM WOOD (BTU/MO) <39>
    WSF     - WOOD STOVE EFFICIENCY <39.3>
```

```
WCTR.KL=DELAY3(WCUTR.JK,WD)                                45, R
WCUTR.KL=LABW.K/HPC                                        45.2, R
WD=1 MONTHS                                                45.3, C
    WCTR     - RATE OF WOOD AVAILABILITY (CORDS/MO) <45>
    WD       - WOOD DELAY TIME <45.3>
    LABW     - WOODCUTTING LABOR (HRS/MO) <48>

MWCP.K=MIN(WGR,CWN)                                        47, A
WGR=ACW*CA                                                 47.1, N
ACW=CIW/DAW                                                47.2, N
CIW=0 $                                                    47.3, C
DAW=200 $/ACRE                                             47.4, C
CA=.1 CORDS/ACRE-MO                                        47.5, C
CWN=TCD/(BTUC*WSF)                                         47.6, N
    MWCP     - MAX WOOD CUTTING POSS (CORDS/MO) <47>
    WGR      - WOOD GROWTH (CORDS/MO) <47.1>
    CWN      - WOOD NEEDED FOR COOKING (CORDS/MO) <47.6>
    ACW      - WOODLOT SIZE (ACRES) <47.2>
    CIW      - CAPITAL INVESTED IN WOODLOT <47.3>
    TCD      - TOTAL COOKING ENERGY DEMAND (BTU/MO) <38.1>
    WSF      - WOOD STOVE EFFICIENCY <39.3>

LABW.K=MIN(LAVW.K,MWCP.K*HPC)                              48, A
LAVW.K=LAVAG.K-LABAG.K                                     48.2, A
HPC=8 HRS/CORD                                             48.3, C
    LABW     - WOODCUTTING LABOR (HRS/MO) <48>
    LAVW     - LABOR AVAILABLE FOR WOODCUTTING (HRS/MO)
                 <48.2>
    MWCP     - MAX WOOD CUTTING POSS (CORDS/MO) <47>
    LAVAG    - LABOR AVAILABLE FOR AGRICULTURE (HRS/MO)
                 <94.3>
```

BUILDING ENERGY SECTOR NOTES

(For complete citation, please refer to bibliography)

1 Although the moderating effect of ground heat can be evaluated in the model, thermal mass cannot. Since it is difficult in any case to provide storage for more than a few days in the structure of the building, it is not clear how this parameter could be incorporated, although it deserves further investigation.

2 A net overall U value of .1 assumes the equivalent of 6" of fiberglass in the walls, 9+ inches in ceilings, double glazed windows with thermal shutters or curtains used 10-14 hours per day, and a window area (primarily south wall) of about 1/5 the total exterior above ground area of the building.

3 All the weather data in this table were determined for a point midway between Portland and Augusta, Maine, with the exception of the ground temperatures which were taken from Bligh, p 92, and are from St. Paul, Minnesota.

The calculation for the outside temperature utilizes a deviation representative of variations of monthly averages from long term means for that month; this produces a more conservative range of temperatures than if daily variations were used. Typically, monthly variances from monthly means can run up to 13°, while daily variations from the mean can be as great as 45°. This is only a factor of three difference and probably will not significantly affect the model behavior, however.

Some of the limitations of randomizing the weather data are obvious. Weather is not completely random, but is somewhat related to what happened the day before and what happens the next day (although the wide diurnal variations in temperatures experienced in Boston recently make this a questionable assumption). The model does not allow long-term weather variations; for the purposes of the short time spans of the model simulations this is probably unimportant.

4 The degree day method is also based on this assumption; degree days are determined from a base of 65°.

5 It might be desirable to incorporate feedback in the building sector to represent measures taken in response to requirements for auxiliary heat. This could take the form of a reduction in the inside temperature desired for a period of time, with a gradual increase as more solar heat became available. This flexibility was not included in the present model.

6 The figure of 300 gal/person-month for GPP represents a daily consumption of 10 gallons per person. This is less than the current consumption of some 15 to 20 gallons but is a realistic figure for an energy conscious consumption. The user can alter this parameter if desired.

7 Makhijani and Poole, pp 111-123. The authors are considering biogas use in terms of rural electrification in India, but considering the thermodynamic properties of the energy in biogas, their conclusions are probably applicable here as well.

8 The value of 292,000 for CEP was determined from figures supplied by Fry and Merrill, p 23, of 12-15 cubic feet of methane required per person per day. It was further assumed that a gas stove would operate at about 80% efficiency, so the figure for CEP represents the net useful energy which must be supplied for cooking. Because the community is supposed to be conservation oriented, the lower value of 12 cubic feet per person per day was chosen as the basis for these calculations.

9 Shelton, p 53, states that that the range of efficiency for most wood stoves lies in the range of 40-65%. A cook stove usually supplies heat to many more places than where the pot is, so 50%, a little lower than the middle of that range, was chosen.

10 Shelton, p 9, states that in natural forests growth rates range from 1/4 to 3/4 cord per acre per year, but could be doubled through management. The rate of growth used in the model for CA, .1 cord per month may be a little high. It is also a little inaccurate to speak of a monthly rate of growth since almost all tree growth takes place in the warm months.

11 According to Central Maine Power figures, the average family in Maine uses some 500 kwh of electricity per month; this figure probably includes some water heating requirements, however. An electricity consumption of 75 kwh/month per person should not be difficult to achieve if water is not heated by electricity. Again, the value of ELUS can be changed by the user.

12 Although there will probably be some demand for electricity 24 hours a day, it is unrealistic to assume that full generator capacity will be required for more than a part of the day. A model structure which permitted 24 hour operation would tend to underestimate the generator size necessary to meet the actual load patterns of a community.

13 The unit generator cost UGC of $200/kwe is open to question. Sears sells generators up to 7 kwe for $170-200/kwe, but their lifetime is not known. Makhijani and Poole, p 113, use a unit cost of $160 but this figure refers to Indian conditions.

14 The efficiency of the gas - electricity conversion is assumed to be 25%; both Fry and Merrill, p 23, and Makhijani and Poole, p 116, suggest this figure is reasonable.

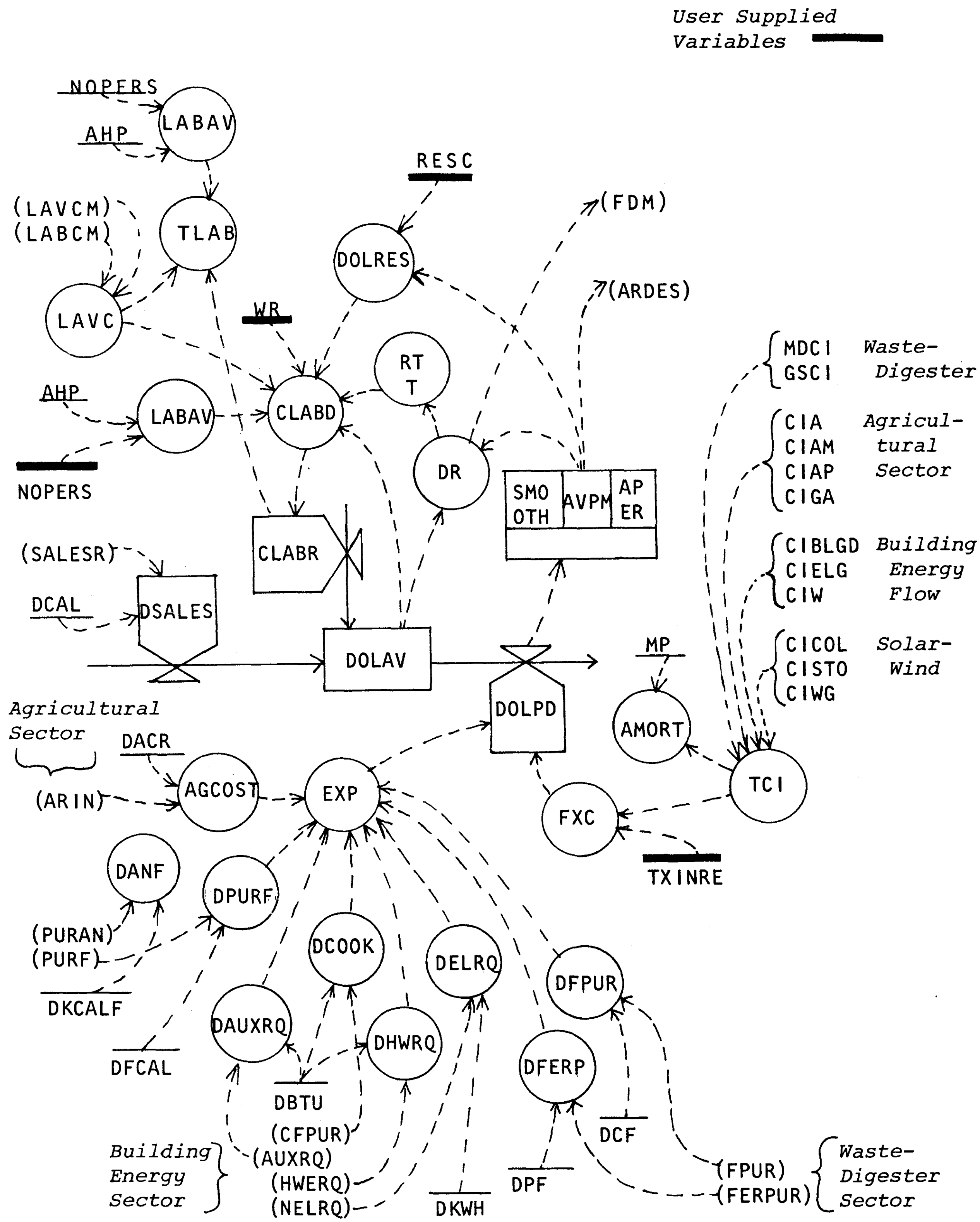
e

Cash-labor Sector

CASH-LABOR SECTOR

The "success" of a particular configuration of the integrated systems model is determined through analysis of the cash-labor sector outputs. It has previously been stated that the community must not only provide for its own food and day-to-day expenses, but must also amortize the investment it has made in all the other sectors. The community has only one source of income open to it - its own labor. Labor can be applied to agriculture to provide food and, indirectly through sales, to augment the available cash. Alternatively, labor can be performed directly for cash; whether cash labor takes place within or outside the community is not considered in this model. Because the community is agriculturally oriented, agricultural labor takes priority over cash labor. This may occasionally result in short-term or long-term deficits, however, since the return from agriculture is delayed several months, while cash is available almost immediately from cash labor. All the community incomes and expenses are brought together in this sector (Fig 33); the net deficit or surplus helps to determine the amount of cash labor and certain agricultural inputs necessary. It is also involved in the determination of the amount of area to be planted.

The only level in the sector, representing cash available DOLAV, is the sum of cash from crop sales DSALES and from labor CLABR, less the monthly expenditures DOLPD. The desired amount of cash on hand DOLRES can be specified by the modeller through the value given for RESC, which is the number of months cash reserve desired. DOLRES depends on an averaged value of past expenditures, rather than current expenditures;



Cash-Labor Sector Flow Diagram
Fig. 33

thus if expenses are increasing, the desired reserve will increase as well. DOLRES is allowed to take on negative values, in practice this represents a deficit. In a rough way this could represent not paying bills on time; besides, agriculture traditionally exhibits cycles of deficit and surplus. Of course, if deficits continue to increase, the community must be judged to have failed in its attempt to achieve self-sufficiency (1).

Income from sales DSALES is the product of the rate of crop sales SALESR and the crop value DCAL (2); crop sales are described with the agricultural sector. The amount of income which is obtained from cash-labor depends on both the amount of cash desired CLABD and the amount of labor available for this purpose. The total amount of labor available for all the community's needs LABAV is the product of the number of persons NOPERS and the average number of hours available from each AHP. The model assumes that half the inhabitants are available to perform labor at a rate of 200 hours per month, thus the average labor availability AHP is 100 hrs/ person-month. Labor other than cash labor OLAB has priority in the community, so the amount of labor available for cash is determined by subtracting OLAB form total labor available LABAV. The result, converted to its cash equivalent by multiplying by the wage rate WR, is compared to the desired labor to determine the amount of cash obtainable from labor CLABI.

The amount of desired cash CLABD is determined from a comparison of the desired cash reserve with DOLAV. If DOLAV is greater than the reserve value, no labor will be necessary, but if DOLAV is less, then the rate of labor desired is the difference between DOLAV and DOLRES, divided by the number of months over which the discrepancy will be made up. Known as the recovery time RT, this factor is determined by the ratio of cash on hand DOLAV to the average expenditures AVPM, also known as the expense ratio DR. RT has a maximum value of 15 months when there is an average of 12 month's required cash on hand and a minimum of three months when there is no cash on hand, regardless of the desired cash reserve (Fig 34). Large values for RT that occur when there is a reasonable amount of cash on hand allow the community to depend on agriculture to make up most of the difference between DOLAV and DOLRES, but when it becomes unrealistic to expect that enough money can be obtained in time through agriculture (because of its three month average delay), the recovery time is shortened to provide more labor for cash (3).

The amount of cash available can also affect the amount of fuel used in agriculture. The fuel use modifier FDM depends on the ratio of cash available DOLAV to the average expenditures AVPM, the expense ration DR. FDM will tend to increase fuel use whenever DOLAV is less than an average 12 month's expenses (Fig 23); this establishes a desired reserve value which is independent of RESC and cash labor considerations. The effect is to use agricultural fuel inputs as a longer term response to cash availability than cash labor, yet the response is faster than the annual determination of the amount of area desired for cultivation ARDES (see agricultural sector).

Total monthly expenditures DOLPD is the sum of amortization AMORT, fixed costs FXC, and energy and food expenditures EXP. Amortization AMORT is calculated from the total capital investment TCI times the unit monthly mortgage payment MP. In this model MP is .00658 dollars per dollar of investment per month, and is based on a 40-year loan at 7.5% interest (4). Fixed costs FXC, such as taxes, interest, replacement, and repairs are also calculated from TCI by multiplying by a given percentage TXINRE (expressed as a decimal). In this model TXINRE is taken as 7% per year, but both TXINRE and MP are alterable by the user.

Total capital investment TCI is simply the sum of all the individual capital investments in the different sectors of the model. Since these are the basic parameters which the modeller will use to alter the structure of the community and are discussed with each sector, I will simply list their abbreviations here rather than name each one: CISTO, CICOL, and CIWG from the solar-wind energy sector; CIGA, CIA, CIAM, and CIAP from the agricultural sector; CIBLDG, CIELG, and CIW from the building energy sector; and MDCI and GSCI from the waste-digester sector.

The total cash expended EXP also comes from purchases made in each sector. The basic purchases, which are expressed in terms of commodities or energy in their respective sectors are converted into their dollar equivalents in the cash-labor sector. Figure 35 lists these dollar equivalents, the conversion factors applied, and the basic purchases:

DESCRIPTION	DOLLAR EQUIVALENT	COMMODITY AND UNITS	CONVERSION AND UNITS
crop expenses	AGCOST	ARIN acres	DACR = $25/acre
animal feed	DANF	PURAN kcal	DFCALF = $.00007/kcal
auxillary heat	DAUXRQ	AUXRQ Btu	DBTU = $.000005/Btu
cooking fuel	DCOOK	CFPUR Btu	DBTU = $.000005/Btu
electricity	DELRQ	NELRQ kwh	DKWH = $.05/kwh
fertilizer	DFERP	FERPUR lbs	DPR = $.0125/lb
fuel	DRPUR	FPUR cu ft	DCF = $.0026/cu ft
hot water fuel	DHWRQ	HWERQ Btu	DBTU = $.000005/Btu
food	DPURF	PURF kcal	DFCAL = $.0005/kcal

Summary of Expenditures
Fig 35. (Notes 5-9)

The averaged monthly payment AVPM, which is used to calculate the expense ratio DR, the cash recovery time RT, and the desired area for planting ARDES, is in actuality a weighted average of the previous year's payments. To achieve an average over one year, the averaging period APER was set at 12 months; since agriculture is cyclical by nature, this appears the most reasonable value. The resulting average is weighted towards the most recent expenses due to the nature of the DYNAMO SMOOTH function used.

CASH-LABOR SECTOR

```
DOLAV.K=DOLAV.J+DT*(CLABR.JK+DSALES.JK-DOLPD.JK)        126, L
DOLAV=DOLA                                              126.1, N
DOLA=14000                                              126.2, C
    DOLAV  - CASH AVAILABLE ($) <126>
    CLABR  - CASH FROM WORK ($/MO) <128>
    DSALES - CASH FROM FOOD SALES ($/MO) <127>
    DOLPD  - TOTAL EXPENDITURES  ($/MO) <138>

DSALES.KL=SALESR.JK*DCAL                                127, R
DCAL=0.00025 $/KCAL                                     127.1, C
    DSALES - CASH FROM FOOD SALES ($/MO) <127>
    SALESR - FOOD SALES <86>
    DCAL   - UNIT CROP VALUE <127.1>

CLABR.KL=CLABI.K                                        128, R
CLABI.K=MIN(CLABD.K,LAVC.K*WR)                          128.2, A
WR=3.5 $/HR                                             128.3, C
CLABD.K=FIFGE(0,(DOLRES.K-DOLAV.K)/RT.K,DOLAV.K,        128.4, A
  DOLRES.K)
    CLABR  - CASH FROM WORK ($/MO) <128>
    CLABI  - EARNINGS ($/MO) <128.2>
    CLABD  - CASH DESIRED FROM LABOR ($/MO) <128.4>
    LAVC   - LABOR AVAILABLE FOR CASH (HRS/MO) <135>
    WR     - WAGE RATE <128.3>
    DOLRES - RESERVE CASH <134>
    DOLAV  - CASH AVAILABLE ($) <126>
    RT     - RECOVERY TIME, MONTHS <131>

RT.K=TABHL(RTT,DR.K,0,12,3)                             131, A
RTT=3/6/9/12/15 MONTHS                                  131.1, T
DR.K=DOLAV.K/(AVPM.K+1E-6)                              131.3, A
    RT     - RECOVERY TIME, MONTHS <131>
    DR     - EXPENSE RATIO <131.3>
    DOLAV  - CASH AVAILABLE ($) <126>
    AVPM   - SMOOTHED MONTHLY PAYMENTS <133>

AVPM.K=SMOOTH(DOLPD.JK,APER)                            133, A
APER=12 MONTHS                                          133.1, C
    AVPM   - SMOOTHED MONTHLY PAYMENTS <133>
    DOLPD  - TOTAL EXPENDITURES  ($/MO) <138>
    APER   - SMOOTHING PERIOD <133.1>

DOLRES.K=AVPM.K*RESC                                    134, A
RESC=0 MONTHS                                           134.1, C
    DOLRES - RESERVE CASH <134>
    AVPM   - SMOOTHED MONTHLY PAYMENTS <133>
    RESC   - RESERVE PERIOD <134.1>
```

```
LAVC.K=LAVCM.K-LABCM.K                                        135, A
    LAVC   - LABOR AVAILABLE FOR CASH (HRS/MO) <135>
    LAVCM  - LABOR AVAIL FOR COMPOSTING (HRS/MO) <78.2>
    LABCM  - COMPOSTING LABOR (HRS/MO) <78>

LABC.K=CLABI.K/WR                                             136, A
    LABC   - CASH LABOR (HRS/MO) <136>
    CLABI  - EARNINGS ($/MO) <128.2>
    WR     - WAGE RATE <128.3>

TLAB.K=LABAV-LAVC.K+LABC.K                                    137, S
LABAV=NOPERS*AHP                                              137.1, N
AHP=100 HRS/PERS-MO                                           137.2, C
    TLAB   - TOTAL LABOR (HRS/MO) <137>
    LABAV  - TOTAL LABOR AVAILABLE (HRS/MO) <137.1>
    LAVC   - LABOR AVAILABLE FOR CASH (HRS/MO) <135>
    LABC   - CASH LABOR (HRS/MO) <136>
    AHP    - AVERAGE UNIT LABOR AVAILABLITY <137.2>
```

EXPENSES

```
DOLPD.KL=AMORT+FXC+EXP.K                                   138, R
DOLPD=8393                                                 138.1, N
AMORT=TCI*MP                                               138.2, N
TCI=CISTO+CICOL+CIWG+CIBLDG+CIGA+CIA+CIAM+CIAP+            138.3, N
  MDCI+GSCI+CIELG+CIW
MP=.00658 $/$-MO                                           138.5, C
FXC=TCI*TXINRE                                             138.6, N
TXINRE=.00583 $/$-MO                                       138.7, C
    DOLPD  - TOTAL EXPENDITURES  ($/MO) <138>
    AMORT  - MORTGAGE PAYMENT ($/MO: 7.5%, 40 YRS)
               <138.2>
    FXC    - FIXED OPERATING COSTS ($/MO) <138.6>
    EXP    - TOTAL ENERGY AND FOOD EXPENDITURES <139>
    TCI    - TOTAL CAPITAL INVESTMENT <138.3>
    CISTO  - CAPITAL INVESTED IN STORAGE <17.5>
    CICOL  - CAPITAL INVESTED IN SOLAR COLLECTOR <8.5>
    CIWG   - CAPITAL INVESTMENT IN WIND PLANT <24.3>
    CIBLDG - INVESTMENT IN BUILDINGS <26.3>
    CIGA   - INVESTMENT IN GREENHOUSE <125.4>
    CIA    - INVESTMENT IN CROPLAND <119.4>
    CIAM   - INVESTMENT IN AGRICULTURAL MACHINERY
               <116.2>
    CIAP   - INVESTMENT IN ANIMALS AND PASTURE <87.4>
    MDCI   - CAPITAL INVESTED IN BIOGAS PLANT <53.8>
    GSCI   - INVESTMENT IN STORAGE TANK <61.4>
    CIELG  - INVESTMENT IN GAS ELECTRICAL GENERATOR
               <35.5>
    CIW    - CAPITAL INVESTED IN WOODLOT <47.3>
```

VARIABLE COSTS

```
EXP.K=AGCOST.K+DANF.K+DPURF.K+DAUXRQ.K+DCOOK.K+        139, A
  DELRQ.K+DHWRQ.K+DFERP.K+DFPUR.K
AGCOST.K=ARIN.JK*DACR                                  139.2, A
DACR=25 $/ACRE                                         139.3, C
DANF.K=PURAN.K*DKCALF                                  139.4, A
DKCALF=.00007 $/KCAL                                   139.5, C
DPURF.K=PURF.K*DFCAL                                   139.6, A
DFCAL=.0005 $/KCAL                                     139.7, C
DAUXRQ.K=AUXRQ.K*DBTU                                  139.8, A
DCOOK.K=CFPUR.K*DBTU                                   139.9, A
DHWRQ.K=HWERQ.K*DBTU                                   140.1, A
DBTU=.000005 $/BTU                                     140.2, C
DELRQ.K=NELRQ.K*DKWH                                   140.3, A
DKWH=.05 $/KWH                                         140.4, C
DFERP.K=FERPUR.JK*DPF                                  140.5, A
DPF=.0125 $/LB                                         140.6, C
DFPUR.K=FPUR.K*DCF                                     140.7, A
DCF=.0026 $/CUFT                                       140.8, C
    EXP    - TOTAL ENERGY AND FOOD EXPENDITURES <139>
    AGCOST - AGRICULTURAL EXPENSES <139.2>
    DANF   - FEED EXPENDITURES ($/MO) <139.4>
    DPURF  - FOOD EXPENDITURES <139.6>
    DAUXRQ - AUXILLARY HEAT <139.8>
    DCOOK  - COOKING FUEL <139.9>
    DELRQ  - NET ELECTRICITY <140.3>
    DHWRQ  - HOT WATER <140.1>
    DFERP  - FERTILIZER EXPENSES <140.5>
    DFPUR  - FUEL EXPENSES <140.7>
    ARIN   - AREA PUT INTO CULTIVATION (AC/MO) <122>
    PURAN  - FEED PURCHASED (KCAL/MO) <83.3>
    PURF   - FOOD PURCHASED (KCAL/MO) <84>
    AUXRQ  - AUXILIARY HEAT REQD (BTU/MO) <31>
    CFPUR  - COOKING FUEL PURCHASES (BTU/MO) <38>
    HWERQ  - HW AUXILIARY HEAT REQD (BTU/MO) <33>
    NELRQ  - NET ELEC PURCHASES (SALES) (KWH/MO) <34>
    FERPUR - FERTILIZER PURCHASES (LBS/MO) <108>
    FPUR   - FUEL PURCHASES (GAL/MO) <115>
```

TIME SECTOR

```
MONT.K=FIFGE(-47,1,MONTH.K,11.8)                       149, A
MONTH.K=MONTH.J+DT*MONT.J                              149.2, L
MONTH=MO                                               149.3, N
MO=12                                                  149.4, C
```

CASH-LABOR SECTOR NOTES

(For complete citations, please refer to Bibliography)

1 The response to deficits or pending deficits in the model is not entirely satisfactory. In the agricultural sector a decrease in food supply leads to decreasing rates of consumption; a similar mechanism might be suitable here. This could take the form of a reduction in use of electricity, more efficient use of water, or lowering the thermostat to save energy, depending on what use was causing the deficit.

Another method of handling deficits would be to model the deficit as an additional loan whose amortization would be added to the usual expenses. One flaw in this approach is its implicit assumption that loans would be available whenever needed.

2 The price per kilocalorie of crop value DCAL is estimated to be .00025 $/kcal; this is intended as an average of the low sales prices for grains, for instance, and the high prices for certain vegetables or milk. At this rate corn would sell for about $25/bushel, which is four to five times the current price, while milk would go for about 62¢/gal, or about one half to one third the current price. As the community is assumed to be engaged in mixed agriculture, this figure will serve, but if the community is to be planned around a specific crop, the modeller should adjust DCAL accordingly.

3 It might also be desirable to model the delays inherent in searching for work and in leaving a job. Since RT causes only a fraction of the discrepency to be made up in any given period, this structure somewhat approximates these delays; their precise representation may be too detailed for the purposes of this mode.

Since cash labor depends on a discrepency between a theoretical cash reserve and actual cash available, in the latter part of a model year after a major harvest and crop sales, there is a possibility of a surplus of cash and thus very little incentive to work. This would happen at a time when a rational planner would determine that, as agriculture was basically out of the picture for a while and cash would be needed in the future, it was an ideal time to work for cash. As available cash decreased in the model, the incentive to work for cash would become strong; about this time, however, agricultural labor would be necessary again. Perhaps a better model would have cash labor respond to an averaged value of available cash.

4 Figures for MP can be obtained from numerous tables supplied by banks or loan companies. A publication in wide use is *Expanded Payment Table for Monthly Mortgage Loans*, prepared by Financial Publishing Company of Boston.

5 Unit crop expense DACR covers seed, sprays, and other expenses.

6 The unit cost of purchased food DFCAL was set at .0005 \$/kcal; this is based on a 3,000 Food calorie (1Food calorie = 1 kcal) daily diet costing about \$10 per week. The unit price of feed in the equation for the cost of animal feed DANF was estimated at .00007 \$/kcal, and represents a grain and feed cost of about \$12 per hundredweight.

7 Oil with a useful energy content of 100,000 Btu/gal and costing 50¢/gal has a unit energy cost DBTU of \$.000005/gal.

8 Using the nutrient content of manure suggested by Pimental *et al*, p 446 - nitrogen 112 pounds, phosphorus 31 pounds, and potassium 60 pounds per 10 tons of manure - and the 1974 prices of these chemicals (Makhijani and Poole, p 112) results in a cost of about \$40 for ten tons of raw manure. This price is also in line with current costs in Maine; thus my choice of cost for an equivalent pound of fertilizer DPF of \$.0125 (\$25/ton) is reasonable.

9 The unit cost of fuel supplements for biogas in the agricultural sector DCF is based on a ratio of biogas to gasoline of 250 cu ft/gal and a gasoline cost of \$.65/gal.

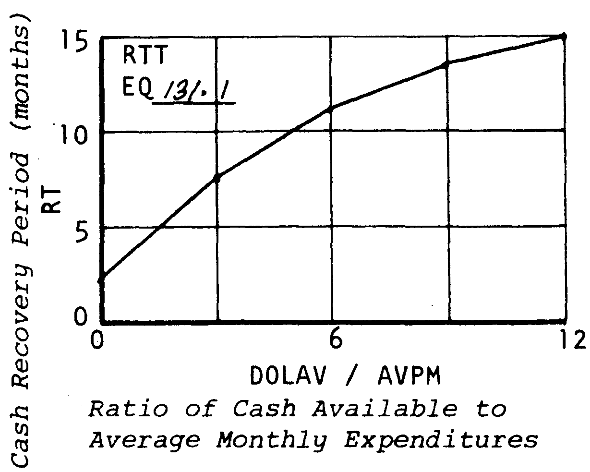


Fig. 34

4
Simulations

To illustrate the use of the model I will describe several rather simple series of runs. Since these are so many parameter variations possible in the model I have limited the parameters to be changed in each series of runs.

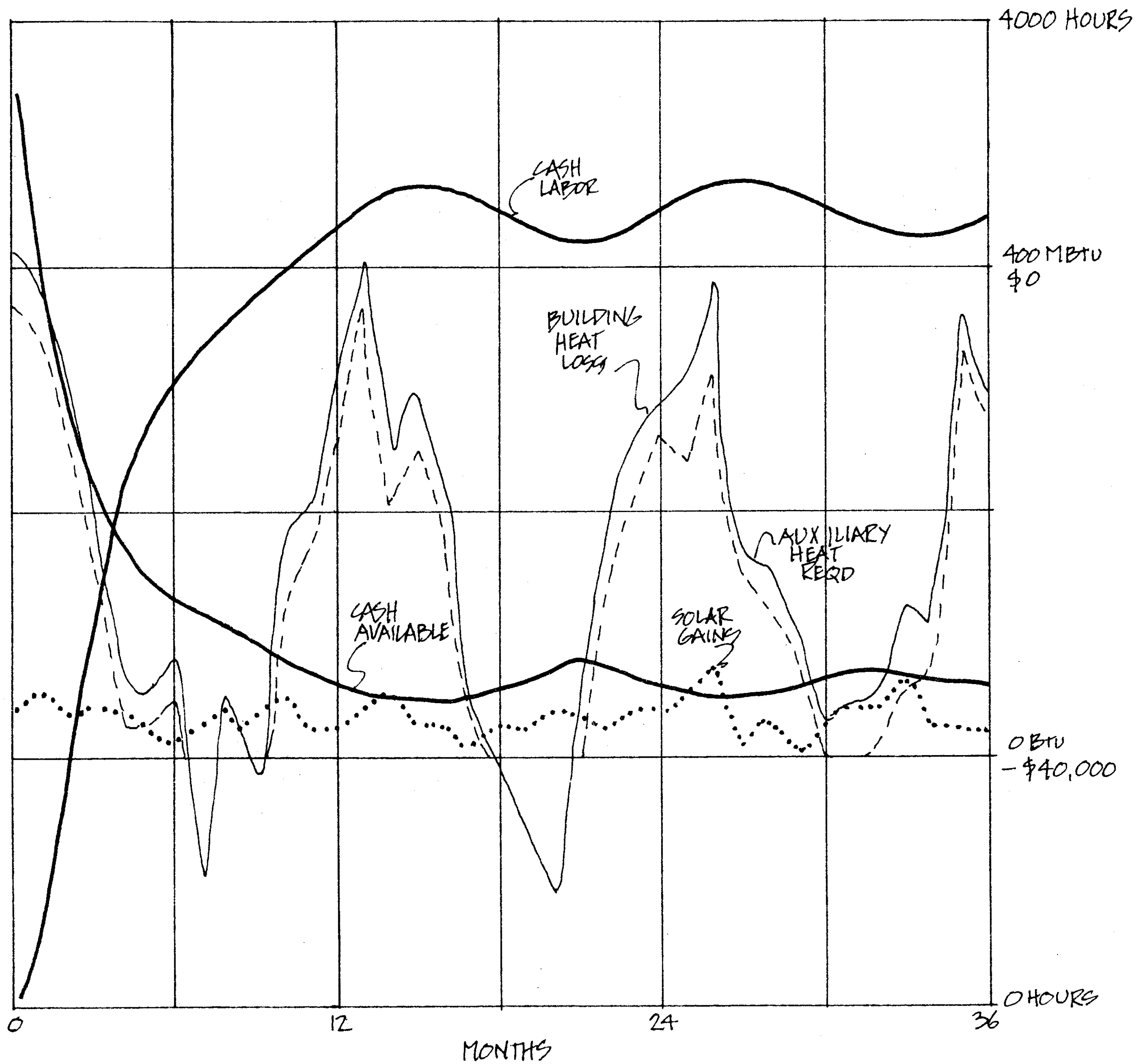
My initial step was to model a community without agricultural, wind energy, active solar energy, or methane digester components. The only parameters left to manipulate were those describing finances, labor, and the buildings. Building parameters were then adjusted to represent what could be a low density community of one story single family houses with normal insulation and fenestration. Under these circumstances the model will simply sum the various expenses - investment and energy - and react to them by means of labor. For the initial run the desired reserve of cash RESC was left at the default value of zero months while building investment CIBLDG was $500,000, building surface area BAREA was 51,000 sq ft, of which south facing windows AWIN accounted for 2,000 sq ft, and the overall U value was .15.

The results are depicted in RUN 1; although the community began with a cash surplus of $14,000, which caused the inhabitants not to work right away (1), it was quickly reduced to a deficit of about $34,000. This is a fairly stable level, however, as the community labor for cash LABC increased to about 3,200 hours per month to offset the monthly payments DOLPD of over $11,000 (2). $6,205 of this represents amortization and fixed operating expenses; the balance goes toward energy and food purchases. The small variations in the level of available cash DOLAV and hours worked are due solely to fluctuations in space heating energy required which, of course, is seasonally dependent. If the community consists of 25 four-person families, a labor requirement of 128 hours per month does not seem unreasonable to provide the basic necessities of life. The use of actual values in these descriptions is only intended to provide a relative basis for comparison of runs. The primary concern of the model is to examine the behavior rather than to try to predict actual values.

The next run examined the effect of improving energy conservation in the community; this was done by increasing the area of south windows, improving the overall U value, and reducing the building surface area. This could represent, for instance, a clustered community of two story attached or semi-attached dwellings which attempts to maximize the passive utilization of solar energy through improved insulation and thermal shutters. It is assumed that the savings associated with the reduced building surface and clustering are offset by additional insulation, window, and shutter costs, thus the building investment CIBLDG remained $500,000. TUVAL was changed to .1, building surface area BAREA was reduced to 35,000 sq ft, of which AWIN represented 7,000 sq ft. The results of these changes are shown in RUN 2.

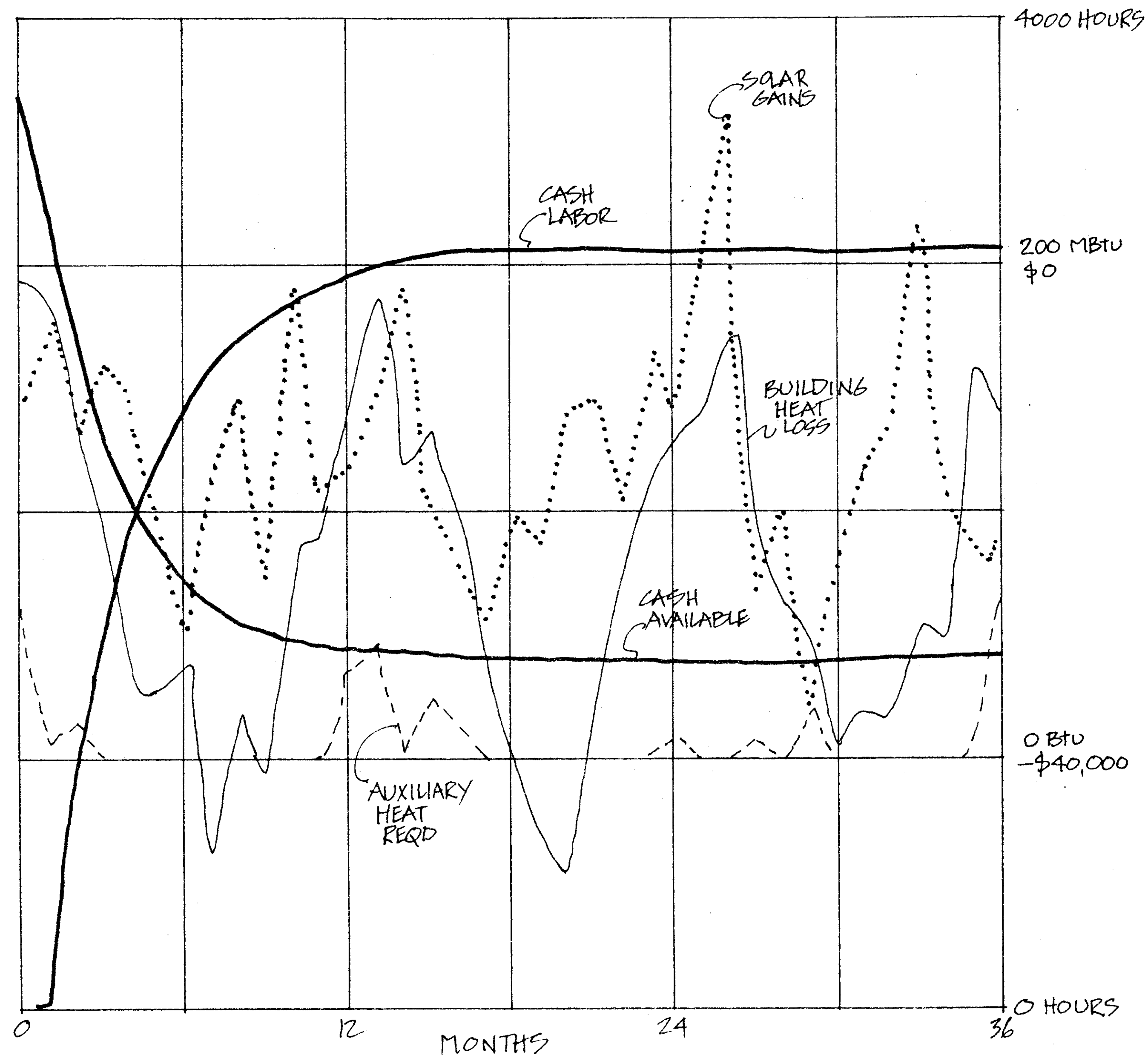
Since no change has been made in the community's response to its financial position, the effect of increasing conservation and passive solar energy utilization is to further stablize the cash level and labor requirements. This is due only to the elimination of most of the variations associated with the heating demands and the substitution of a steady amortization of investment. The community now stabilizes at slightly less than a $32,000 deficit with only about 3,040 hours per month re-

RUN 1

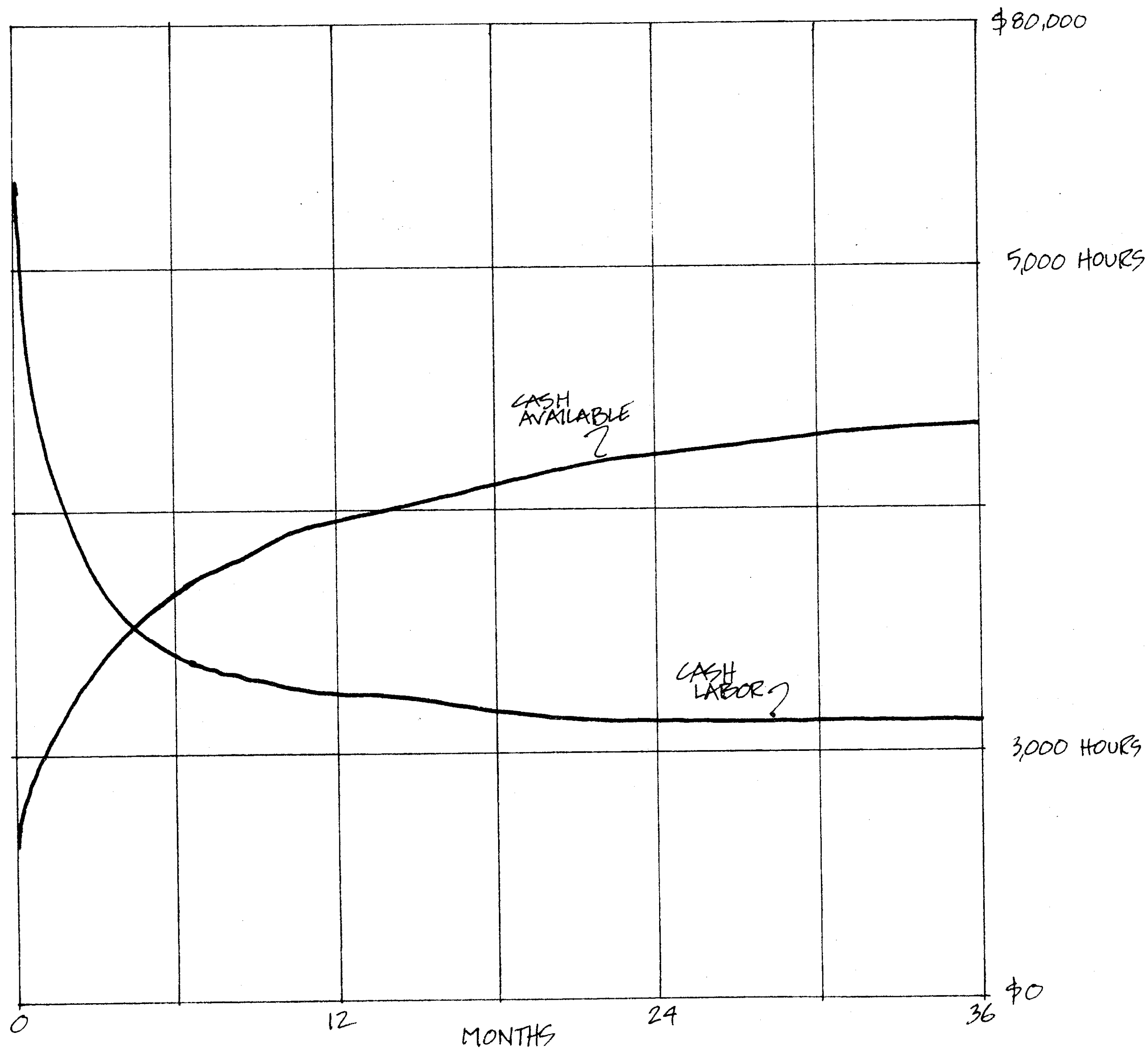


4000 HOURS
400 MBTU
$0
0 BTU
-$40,000
0 HOURS
CASH LABOR
BUILDING HEAT LOSS
AUXILIARY HEAT REQD
CASH AVAILABLE
SOLAR GAINS
0
12
24
36
MONTHS

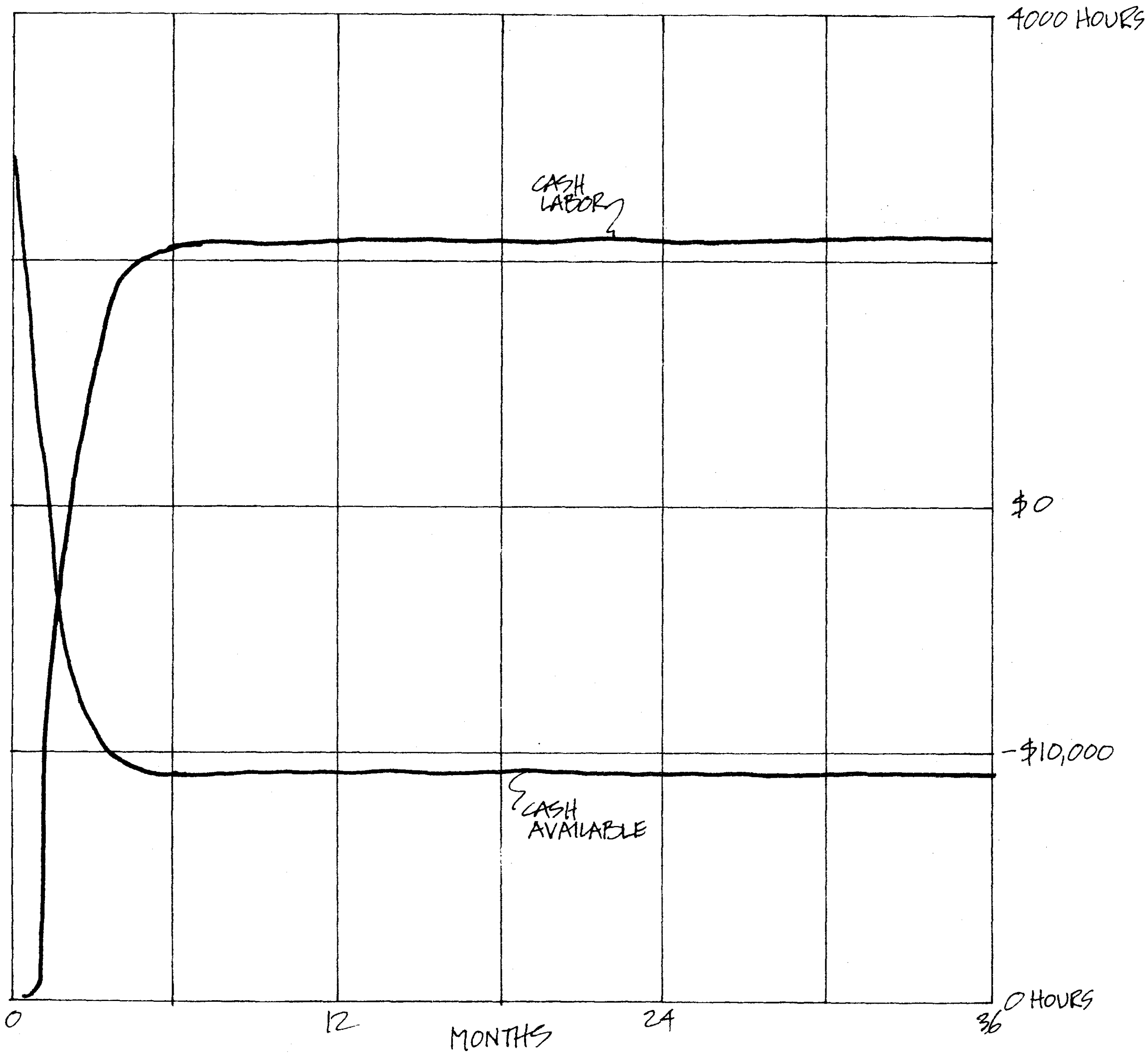
RUN 2


4000 HOURS
SOLAR GAINS
CASH LABOR
200 MBtu
$0
BUILDING HEAT LOSS
CASH AVAILABLE
0 Btu
-$40,000
AUXILIARY HEAT REQD
0 HOURS
0
12
24
36
MONTHS

RUN 3


$80,000
5,000 HOURS
CASH AVAILABLE
CASH LABOR
3,000 HOURS
$0
0
12
24
36
MONTHS

RUN 4


4000 HOURS
CASH LABOR
$0
-$10,000
CASH AVAILABLE
0 HOURS
0
12
24
36
MONTHS

quired to offset expenses of $10,700 per month. A full analysis of the trade-offs between the two schemes must also take into account their social implications.

The effect of setting a 12-month desired level of cash reserve as a goal for the community was next examined; this is illustrated in RUN 3. The cash level now rises as the community begins to work at a high rate immediately (2). Expenses are no different than the previous run so even though this run was not carried out long enough it can safely be assumed that the amount of labor required will eventually stabilize at about the same number of hours. The cash level attained will be about $48,000, only about a 4.8 month reserve, however. This is due to the effect of another mechanism in the model which controls the community's response to its financial position and which I have called the recovery time RT.

Although the reserve cash period RESC sets a goal, the recovery time determines how fast the community works toward that goal, depending only on a comparison of available cash with the average monthly expenditure. RUN 4 illustrates the results of shortening RT (RTT = 1/1/3/5/7 instead of RTT = 3/6/9/12/15 months) while keeping the reserve period RESC at zero. The community deficit stabilizes at just over $10,000, while labor is, again, about 3,040 hours per month. The amount of deficit at which the model stabilizes is clearly only a function of how fast the community responds to its financial position. While the model makes implicit assumptions about the nature of this response, these assumptions could be investigated in more detail than has been done in the course of making the model. Such study may show, for instance, that a very fast recovery time is an unrealistic representation of the actual process of determining the financial situation and taking the steps to deal with it, such as searching for a job.

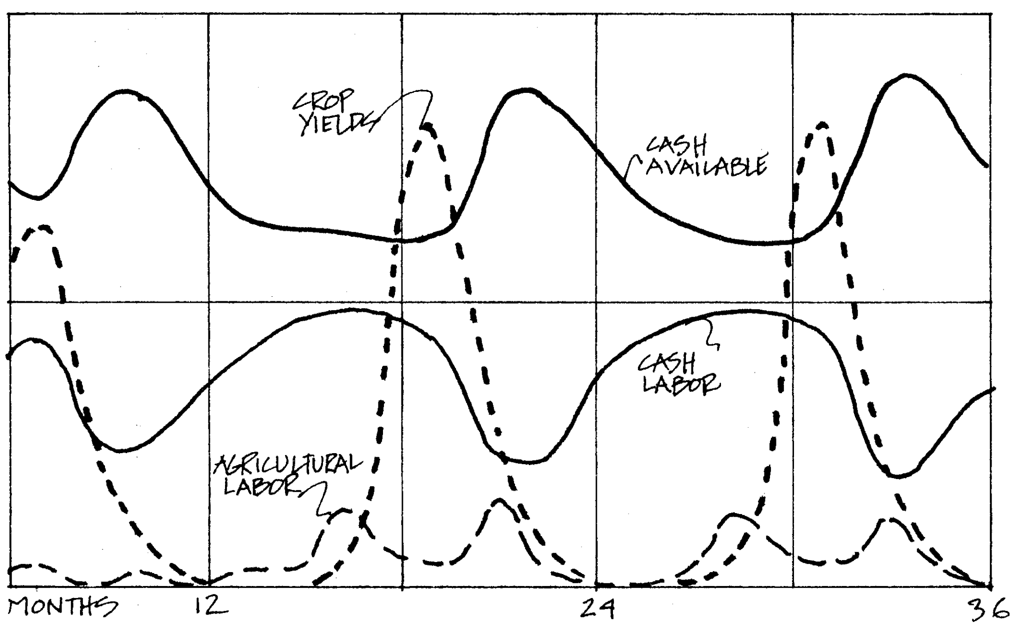
By manipulating RT and RESC one can obtain nearly any net cash balance one desires, even if its relation to reality is uncertain. If the faster recovery time described above is combined with a desired cash level of 12 months, for example, the effect is again a speedy response to the financial position which tapers off to about 3,040 hours of labor per month but with a cash surplus of $80,000. If all that is desired is to avoid an apparent deficit, a reserve period RESC of 4 months will work, even with the slower response time.

Once the desired financial structure has been determined, the other parameters in the model can be altered. Since the community is intended to have an agricultural base, I will next discuss the introduction of these agricultural parameters to the basic model. In this series of runs I maintained the lower surface area and the improved insulation of the previous runs, but decreased window to the original 2,000 sq ft. The reserve period RESC was also left at zero. The resulting behavior, without agriculture, looks very much like that of RUN 1, except labor fluctuates slightly about 3,100 hours, rather than 3,200, and the deficit is slightly less. Because of the conservation measures taken the seasonal fluctuations are somewhat less, and monthly expenditures average about $500 less than in the earlier run.

The addition of agricultural elements causes striking variations to appear in the cash level and in cash labor behavior, this is illustrated in RUN 5, and summarized in Table 1. In this run the agricultural investment values, CIA = \$24,000, CIAM = \$3000, CIAP = \$22,400, and CIGA = \$25,000, respectively represent a total cultivable area of 80 acres, the presence of enough agricultural machinery to enable the use of fuel in agriculture, 16 dairy cows and 32 acres of positive and hayfields, and 10,000 square feet of greenhouse.

The fluctuations in the output curves are due, of course, to the seasonal character of the agriculture practical in New England and most north temperate climates. In this set of runs the community is involved in agriculture only to a limited extent (3); as a result, only about 1/5 of the community's total cash requirements are met in this way. The results of the inclusion of agriculture are shown in RUN 5. Because the initial period of transition to a steady state depends on the given initial values of equations in the model, in general only the second and subsequent years will be depicted in these illustrations, as the points I wish to make are related to the steady state rather than to the startup conditions.

The addition of agriculture results in a reduction by about 1,100 hours in the amount of cash labor; this is offset in part by 250 hours of labor required for agriculture. Average monthly expenditures are reduced by about \$2,350 to \$8,500 even though amortization and other fixed costs have risen to \$7,128; this is due to the production of food, the largest single community expense in the absence of agriculture. Of course, the favorable crop price and the not-so-favorable wage rate which are the default values in the model contribute to this rosy picture, but these values can be changed to present a more pessimistic outlook, if it is desired; the psychological and social value of producing one's own food must also be considered in the analysis of these trade-offs.



RUN 5

RUN	LABC cash labor	LABAG agric labor	YLDR yield rate	per acre yield	DOLPD total expenses	FXC + AMORT	EXP variable expenses	DSALES crop sales
5	3,100 hrs	0 hrs	0	0	10,855	6,205	4,650	0
A1	2,000	250	17.8 M kcal	6.9	8,500	7,130	1,370	1,470
A2	1,980	244	19.3	7.5	8,530	7,280	1,250	1,570
A3	2,006	244	19.6	7.7	*	7,330	*	1,580
A4	2,260	253	20	*	9,620	8,370	1,250	1,715

5: no agriculture; CILDG = 500,000, AWIN = 20,000, TUVAL = .1, RESC = 0

A1: basic agriculture; CIA = 24,000, CIAM = 3,000, CIAP = 22,400, CIGA = 24,000 plus parameters of RUN 5

A2: agriculture and biogas; MDCI = 10,000, GSCI = 2,000 plus parameters of RUN A1

A3: agriculture and biogas with increased gas storage; GSCI = 6,000 plus other parameters of RUN A2.

A4: agriculture and large biogas; MDCI = 60,000, GSCI = 40,000; plus parameters of RUN A1.

* This output was not available.

Table 1. Summary of Agricultural Runs

The addition of a biogas plant to the basic agricultural structure (MDCI = $10,000, GSCI = $2,000) does not change the basic pattern of behavior, but it does affect some of the output values. Since the basic behavior is the same as the previous run I have not shown it separately; the outputs of this series of agricultural runs are summarized in Table 1. Average expenditures are slightly increased, due to increased amortization costs, but variable operating expenses, primarily for fuel, are decreased, as are requirements for both cash and agricultural labor. This comes about because crop yields increase by about 8%, from an average of 17,800,000 kcal to 19,300,000 kcal per month, and crop sales increase over $100 per month.

The addition of a larger gas storage tank, in order to make it possible to store more gas from peak periods of production for use much later in agriculture, increased yields only slightly. It must be noted that the digester is already somewhat larger than necessary for the community's waste output. The maximum loading capacity is, on the average, over two times as great as the amount of material actually available (if the community was make its entire living from agriculture this digester would be undersized, however, 3). While the initial addition of a digester decreased the total labor expended for cash and agriculture, the additional amortization costs of the larger storage must be made up by increased cash labor since the increase in yields and sales is insufficient for this purpose.

As an experiment, a vastly oversized digester and storage combination was entered in one run (MDCI - $60,000; GSCI = $40,000). As expected, there was very little additional yield, a slight increase in agricultural labor, and a greatly increased requirement for cash labor (+250 hours), necessary to offset over $1,000 in increased amortization and fixed costs.

All these runs exhibit a drop off in cash labor after agricultural sales have augmented the level of cash. I discussed the reasons for this probable occurence with the cash-labor sector; although I attempted to minimize the effect by making labor partially dependent on average values of expenses, it probably would have been more effective to utilize average values of cash available.

I also investigated the effect of reducing the crop area available to the community by a factor of four. Since the community utilizes less than 50% of the total area available given the default values in the model, the effect was not as great as I had expected. However, agricultural labor increased by a factor of three, to over 900 hours per month; cash labor also increased, but by only 18%. While the amount of land put into cultivation was only 55%, on the average, of that put in when the greater area was available, the average crop yield was 65% of that formerly obtained. This was due to the increased yield per acre caused by greatly increased agricultural labor per acre. These results are summarized in Table 2; the figures cannot be compared directly to the other agricultural runs described above because values for RESC and AWIN are different (here RESC = 4; AWIN = 5,000 sq ft).

	LABC cash labor	LABAG agric labor	YLDR yield		ARIN area
full area	1,970 hrs	300 hrs	20.7 M kcal	(7.1 M kcal/acre)	2.9 acres/mo
reduced area	2,320	940	13.6 M	(8.4 M)	1.6

Table 2

A comparison was made, without agricultural components, of the benefits of investing a relatively small amount of capital, $20,000, in either a solar collector or a wind generator. I further compared the effect of increasing the investment in the wind generator to $40,000 and $100,000. The building surface area, window area, and U value were given non-conservative values (BAREA = 51,000 sq ft; AWIN = 2,000 sq ft; TUVAL = .15) and the cash reserve period was zero; results of these comparisons are given in Table 3.

While the investment in a small wind generator (approximately 26kwe rating) appears to be a better investment than the same amount invested in solar energy, this may be due to factors in the model not entirely accurate to real life. The wind speed data in the model is slightly on the optimistic side since it was taken from coastal data, while the solar data from an inland location is probably more accurate. The investment-capacity relationships in the model are probably more realistic for solar energy than for wind since there is much more experience in manufacturing and marketing solar collectors than wind generators.

	LABC cash labor	DOLPD monthly expenses	DELRQ elec reqd (sold)	DAUXRQ aux. heat expenses
solar	3,274 hrs	$11,455	$375	$574
26 kwe wind	3,254	11,362	208	649
60 kwe wind	3,275	11,401	0	649
140 kwe wind	3,348	11,565	(582)	649

Table 3

The comparisons between the increasing wind energy investments are probably more realistic, since the calculations are internally consistent. Thus, with an investment of $40,000 in a 60kwe generator the community becomes virtually self-sufficient in electricity production (assuming the surplus can be sold). As much is generated as surplus as is purchased, and the overall average monthly payment is only about $40 greater than with the small generator; for some persons this would be a small price to pay for the feeling of self-sufficiency. This picture may also depart from reality since it depends on electricity being sold at the same price as it is purchased. Small changes in this price would not affect the order of magnitude of generator size necessary to break even, however.

The $100,000 investment in a 140kwe generator, however, results in increased monthly expenditures of $165 despite the sales of over 1 1/2 times the amount of electricity used in the community itself. Aside from probable legal restrictions on the generation of such great surpluses, the community is much more vulnerable to disruption with such a large generator, since it is dependent on the generator not only for its own electricity needs, but also for sales to offset the investment.

Since the primary objective of the community integrated systems model is to provide a method which permits the exploration and evaluation of behavior resulting from different allocations of investment in alternative energies, I made a further series of model runs in which the total investment was held nearly constant but was allocated in five different ways. The basic building investment remained at $500,000 in each run while a total of $200,000 was allocated to the various alternative energies possible in the model, including solar energy, wind energy, wood, and biogas components. The investments and all other parameters changed in each run are summarized in Table 4; due to errors at the console the total additional investment is not exactly $200,000 in two of the runs.

For this series of runs the model has been adjusted so that the community will take full advantage of the crop area available to it, thus these runs cannot be directly compared to the runs described previously. As this adjustment was made to correct an internal error in the model, its explanation is not necessary. The run of the basic agricultural and building components displayed behavior similar to that described earlier in this chapter (see BASIC run). There is a difference, however, in that most of the community's expenses are now covered by the income from crop sales, and little cash labor is required. Agricultural labor requires about 2180 hours per month, on the average, while cash labor is only about one quarter as great. The average monthly output values for each run are presented in Table 5.

Parameter	BASIC buildings and agriculture	MIX 1 agriculture with major solar, some methane	MIX 2 agriculture solar, wind, and wood	MIX 3 agriculture major methane, wind, some solar	MIX 4 agriculture increased crop area	MIX 5 agriculture building energy conservation
CIBLDG	$ 500,000	$ 500,000	$ 500,000	$ 500,000	$ 500,000	$ 500,000
BAREA	51,000	51,000	51,000	51,000	51,000	51,000
AWIN	2,000	2,000	2,000	2,000	2,000	2,000
TUVAL	.15	.15	.15	.15	.15	.08
CIA	$ 24,000	$ 24,000	$ 24,000	$ 24,000	$ 48,000*	$ 24,000
CIAM	3,000	3,000	3,000	3,000	3,000	3,000
CIAP	22,400	22,400	22,400	22,400	22,400	22,400
CIGA	25,000	25,000	25,000	25,000	25,000	25,000
CICOL	0	120,000	120,000	60,000	60,000	100,000
CISTO	0	60,000	60,000	15,000	15,000	50,000
CIWG	0	20,000	70,000	0	0	0
CIELG	0	0	0	0	5,000	0
MDCI	0	10,000	0	40,000	49,000	10,000
GSCI	0	2,000	0	15,000	15,000	2,000
CIW	0	8,000	8,000	0	8,000	8,000
total additional investment		200,000	208,000+	200,000	176,000+	200,000

CIBLDG=building investment; BAREA=building surface area; AWIN=south window area; TUVAL=overall building U-value; CIA=investment in crop area; CIAM=investment in agricultural machinery; CIAP=investment in animals; CIGA=investment in greenhouse; CICOL=investment in solar collector; CISTO=investment in solar storage; CIWG=investment in wind generator; CIELG=investment in gas electric generator; MDCI=investment in methane digester; GSCI=investment in gas storage; CIW=investment in woodlot.

+ these are not exactly $ 200,000 because of an error at the console

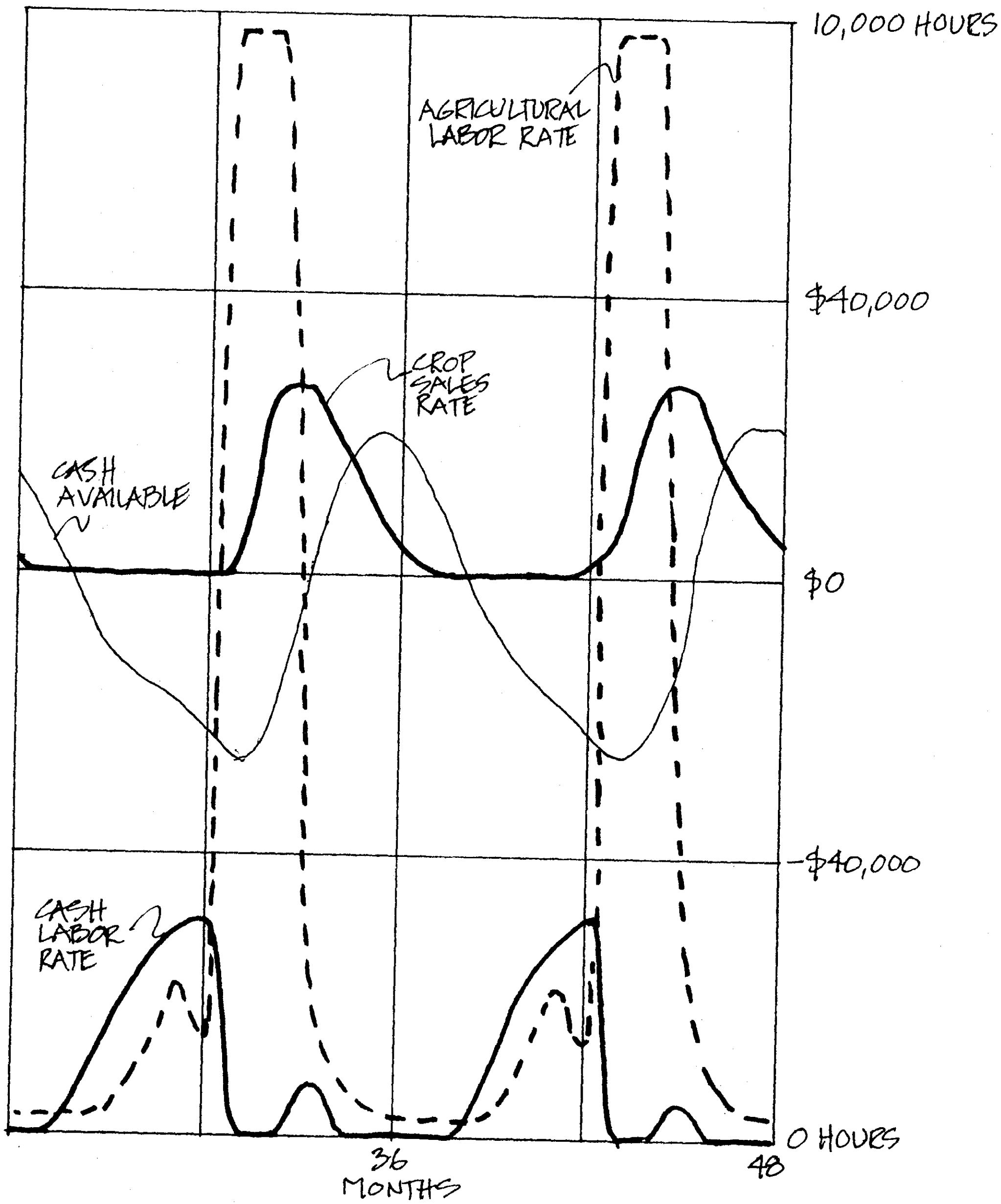
* the table TOTART must also be changed to correspond with the altered crop area

Table 4. Summary of Different Investment Allocation Runs

caution: errors of omission cause columns to add wrong
CH. 25NOV77

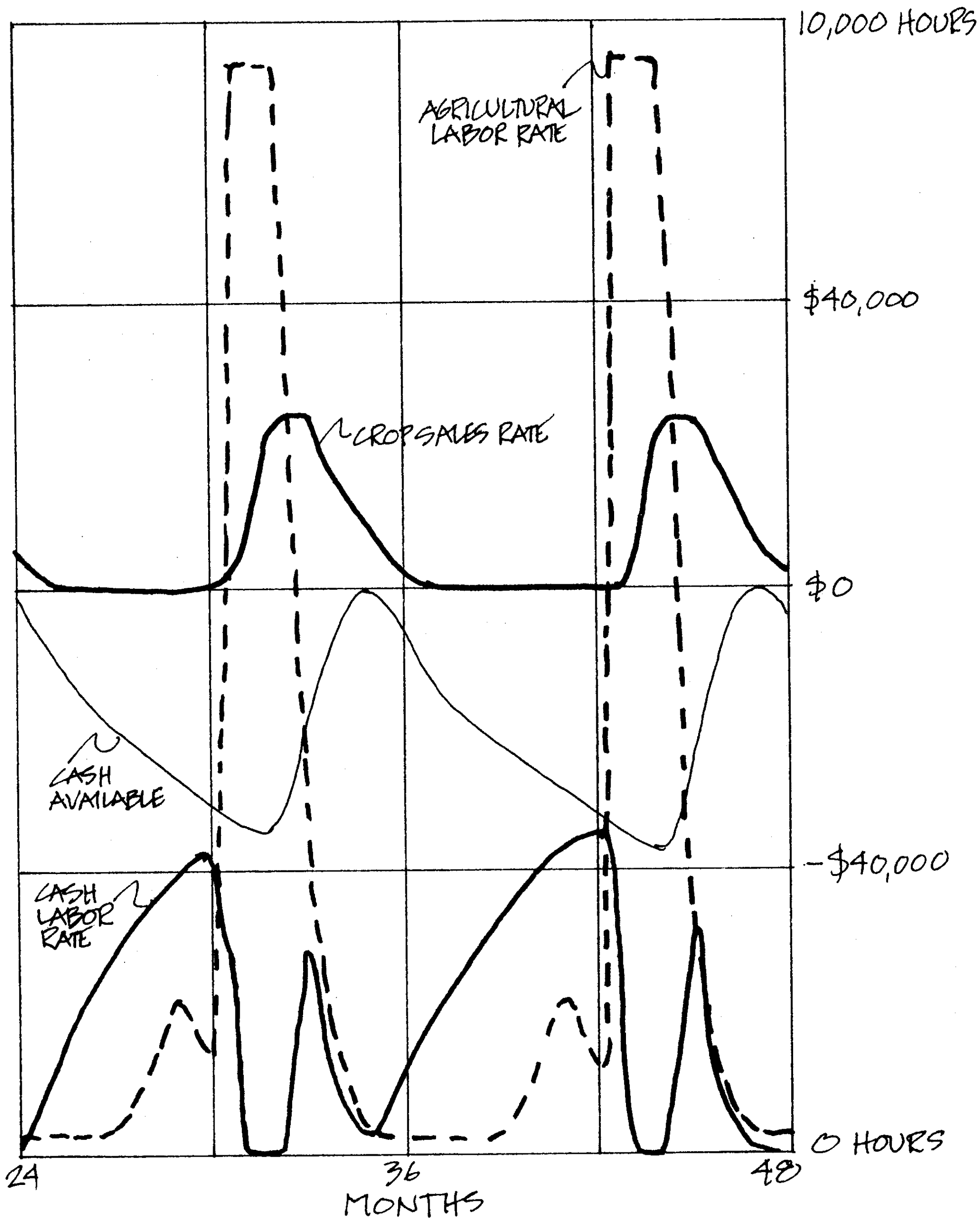
run	LABC cash labor	LABAG agric labor	LABMD digester labor	YLDR yield rate	DOLPD total monthly expenses	FXC + AMORT	DSALES crop sales
BASIC	530 hrs	2180 hrs	0 hrs	44.7 M kcal	$8985	$7129	$7200
MIX 1	1240	2150	70	40.7	10715	9610	6230
MIX 2	1030	2180	0	44.7	10675	9710	7200
MIX 3	1170	2150	70	41.8	10425	9610	6460
MIX 4	250	1080	80	51.8	10415	9312	8670
MIX 5	1210	2150	70	40.7	10605	9610	6230

Table 5. Average Monthly Outputs for Investment Allocations



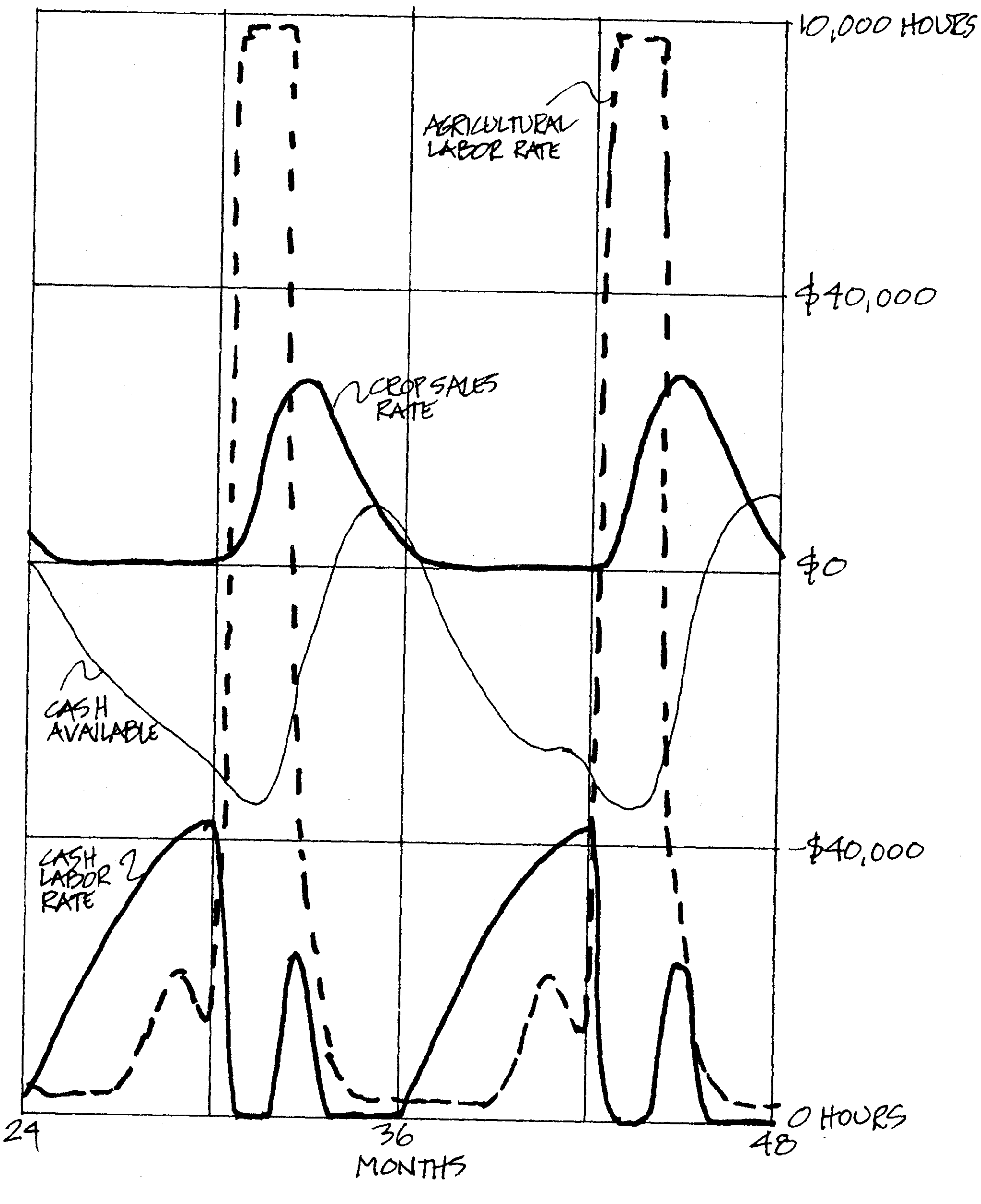
10,000 HOURS
AGRICULTURAL LABOR RATE
$40,000
CROP SALES RATE
CASH AVAILABLE
$0
-$40,000
CASH LABOR RATE
0 HOURS
36
MONTHS
48

BASIC

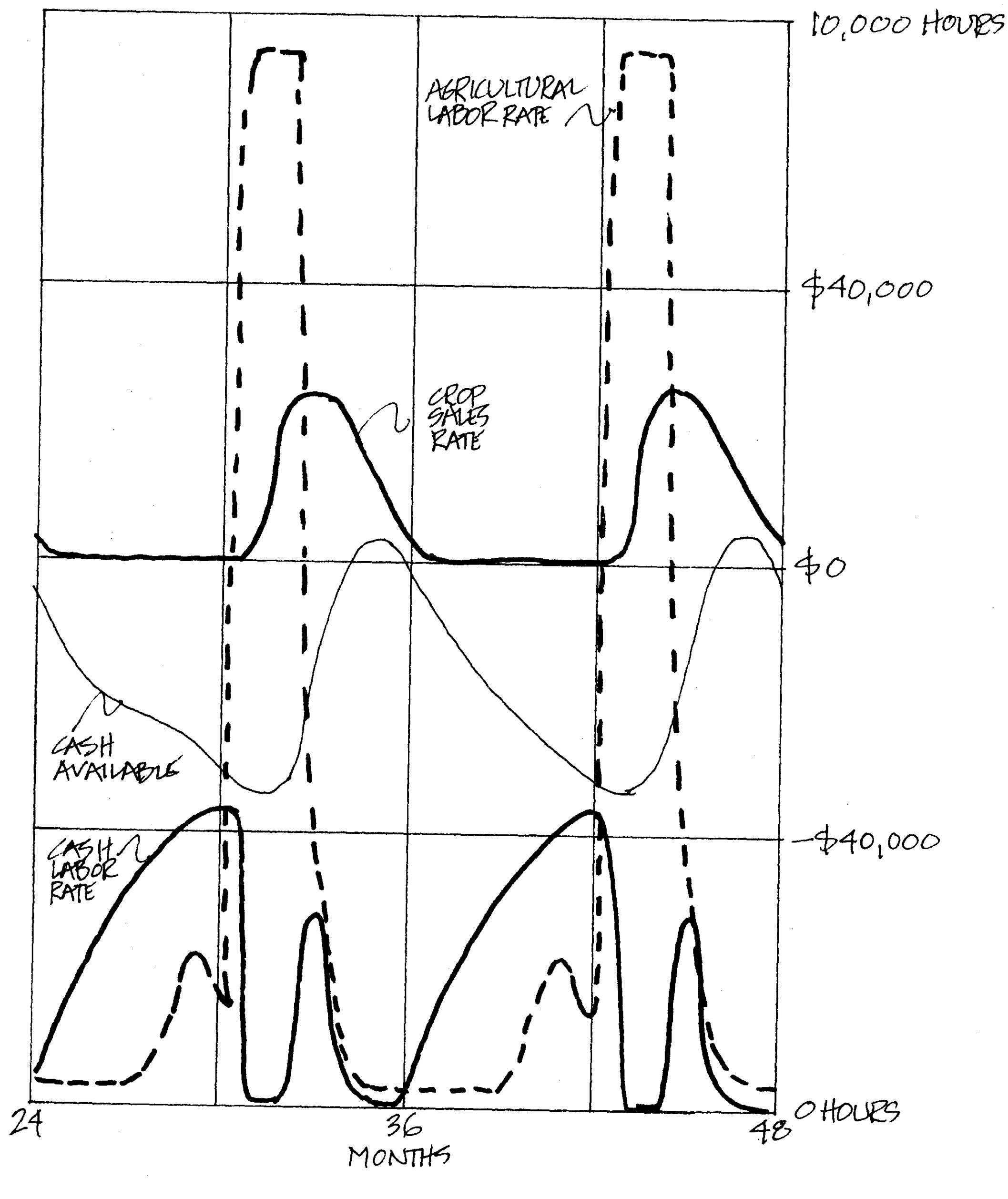


10,000 HOURS
AGRICULTURAL LABOR RATE
$40,000
CROP SALES RATE
$0
CASH AVAILABLE
-$40,000
CASH LABOR RATE
0 HOURS
24
36
48
MONTHS

MIX 1

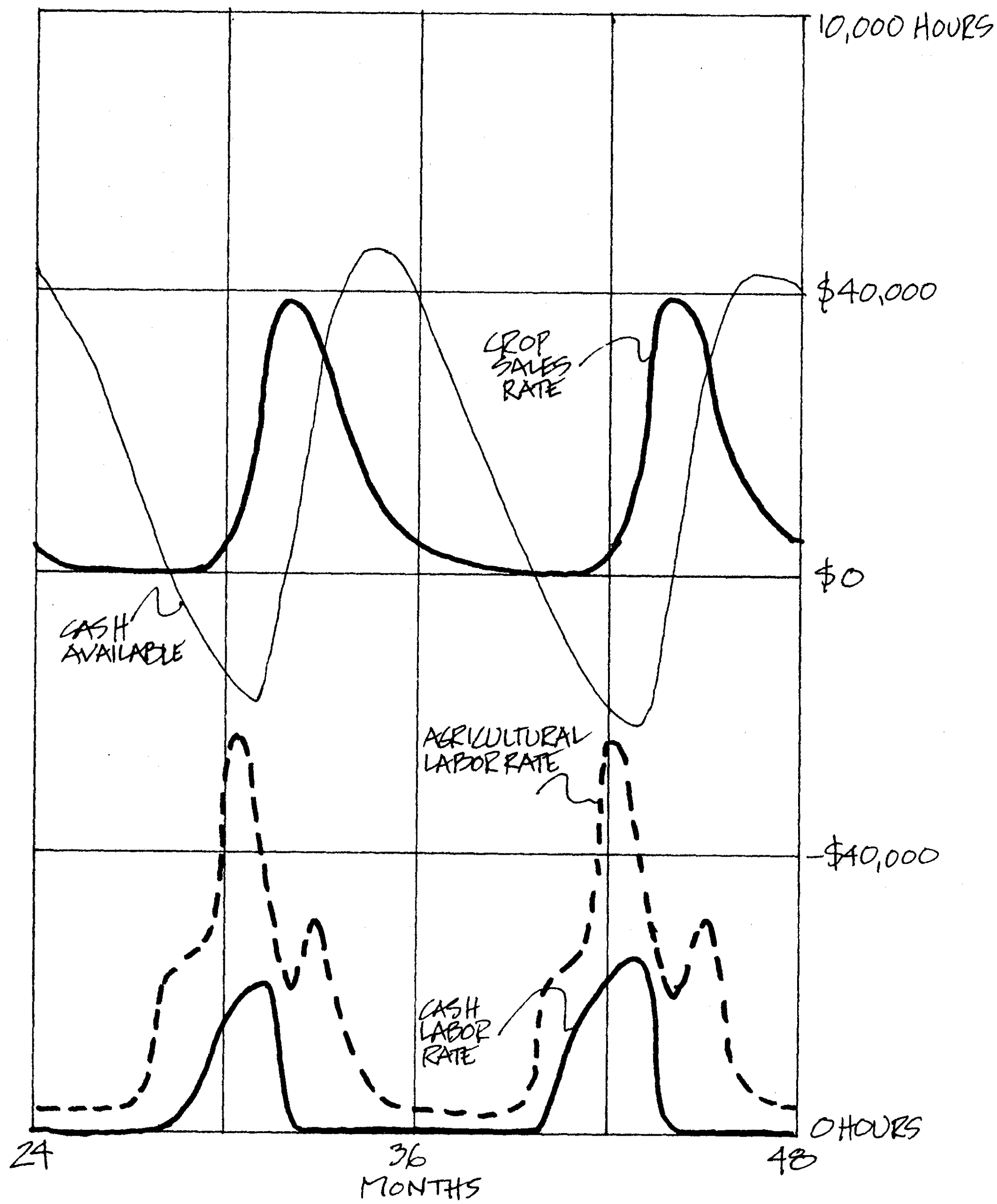

10,000 HOURS
AGRICULTURAL LABOR RATE
$40,000
CROP SALES RATE
$0
CASH AVAILABLE
-$40,000
CASH LABOR RATE
0 HOURS
24
36
48
MONTHS

MIX 2

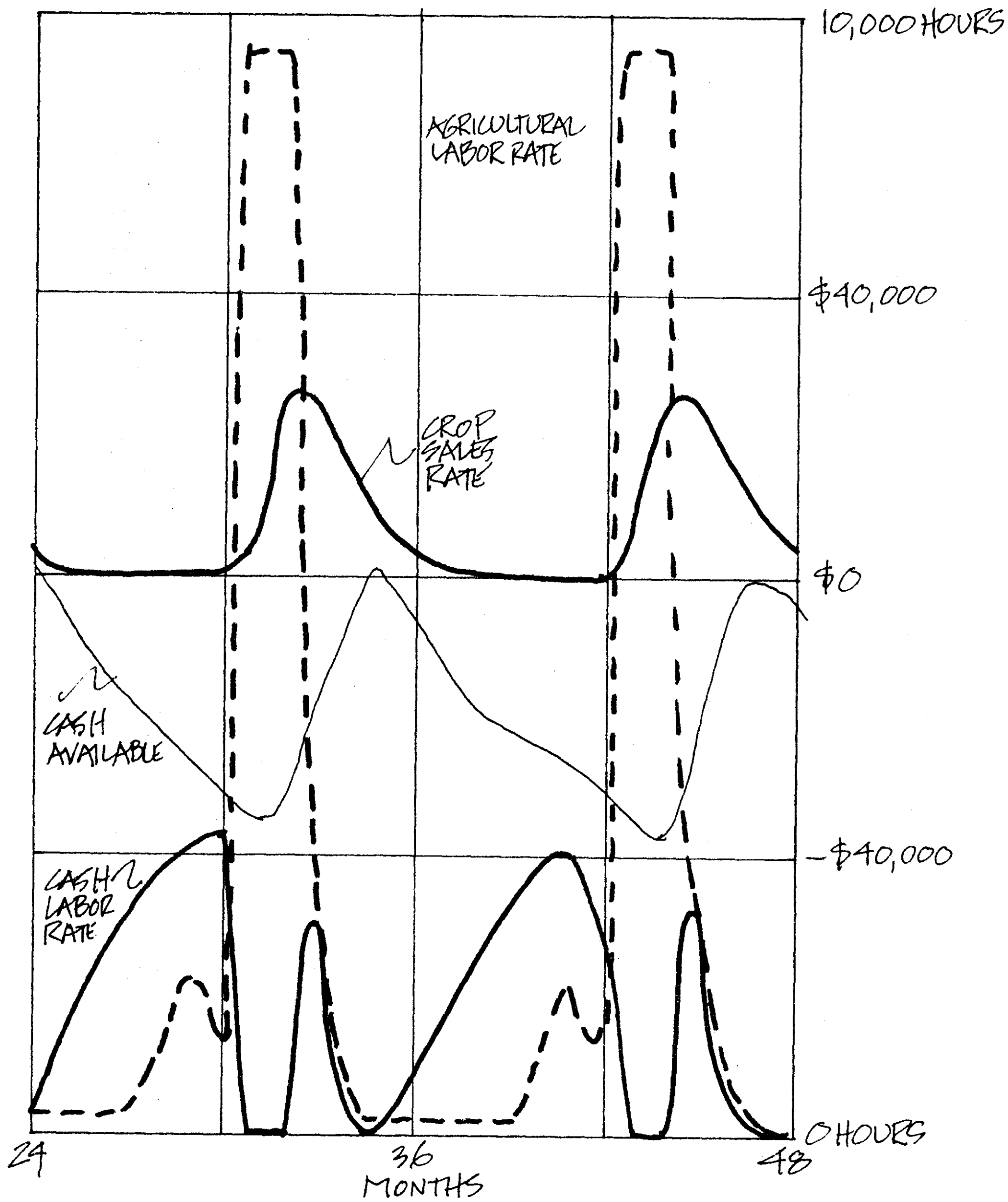


10,000 HOURS
AGRICULTURAL LABOR RATE
$40,000
CROP SALES RATE
$0
CASH AVAILABLE
-$40,000
CASH LABOR RATE
0 HOURS
24
36
48
MONTHS

MIX 3


10,000 HOURS
$40,000
CROP SALES RATE
$0
CASH AVAILABLE
AGRICULTURAL LABOR RATE
-$40,000
CASH LABOR RATE
0 HOURS
24
36
48
MONTHS

MIX 4



10,000 HOURS
AGRICULTURAL LABOR RATE
$40,000
CROP SALES RATE
$0
CASH AVAILABLE
-$40,000
CASH LABOR RATE
0 HOURS
24
36
MONTHS
48

MIX 5

The addition of a $200,000 investment, primarily in solar energy, but including a small methane digester and woodlot, results in slightly decreased values for agricultural labor but a more than doubled amount of cash labor required (see MIX 1); yields are also down slightly. This result puzzled me until I recalled that I had assigned labor for the digester priority over agricultural labor, since I assumed that the operation of a digester would suffer if it was not constantly attended. I had also assumed that the actual amount of digester-related labor required would be quite small in relation to agricultural labor. As it turns out, the community is limited in agriculture by its crop area (80 acres), a fact I did not discover until this series of runs; thus the slightly lower amount of labor available for agriculture because of the digester labor requirements ultimately results in a lower yield, even though the community plants the same amount of land.

This unexpected behavior could be spurious, only a result of a false assumption, or it could represent a potential conflict for a community with a committment to agriculture and a desire to incorporate a digester. The possibility that the assumption may be inaccurate bears investigation, but if it is found to be valid, perhaps a community policy could be devised to allow deferment of the digestion of part of the large volume of waste material which becomes available during the peak period of agricultural labor. This might entail an additional investment or a committment of land for storage of the surplus, however.

Shifting the investment from methane to a small wind generator of 26 kwe capacity, while maintaining the same investment in solar energy, results in yields the same as in the basic agricultural run (see MIX 2). This is to be expected, as the model does not require any labor for wind generation of electricity. Since the community cannot expand its agricultural operation it increases its cash labor to about two times the rate of cash labor in the basic run.

The third run (MIX 3) involved the reduction of the investment in solar energy to $60,000 for the collector and $15,000 for storage. The wind generator investment was increased to $70,000; earlier in this chapter it was suggested that an investment in wind energy of about this magnitude would make the community self-sufficient in electricity. A large biogas plant was also added, with $40,000 invested in the digester and $15,000 in gas storage. Total expenditures are about $200-300 less per month than either of the first two investment mixes, but cash labor requirements are about 13% greater than for the community without the digester.

MIX 4 maintained solar and digester investments approximately the same as in MIX 3, but eliminated the wind plant and substituted a small gas-electric generator; the investment in agricultural land was increased to $48,000, doubling crop area, and $8,000 was allocated for a 40 acre woodlot to supply cooking fuel. In this series of runs, this appears by far the best investment allocation. In the other runs the community was required to expend considerable labor in agriculture because it was limited in crop area but at the same time desired high yields. Doubling the available crop area cut the amount of labor required for both agriculture and cash by 50%. The labor required for the operation of the methane digester did not increase significantly and is only about one third as great as cash labor requirements.

In the last run of this series (MIX 5) the methane digester and storage components were reduced in size to those in MIX 1. No investments were made in electrical generation, but a 40 acre woodlot was included. While solar energy represented a sizable part of the total investment, $30,000 was invested in building energy conservation, representing additional insulation, quality control, and thermal shutters for the windows. These changes did not alter the model behavior much although slightly more cash labor was expended than in runs with wind energy components. The amount of agricultural labor remained about the same, since the community is limited by crop area. Average monthly expenditures were greater than in the run with the large wind generator (MIX 3) or the run with increased crop area (MIX 4), but were less than the runs with the small wind generator (MIX 2) or with the small biogas plant and woodlot (MIX 1). It is not clear that any conclusions can be drawn from these slight differences in values.

In order to make more sense of the behavior of the different runs it would be desirable at this point to make a detailed analysis of the role each component plays in the community. One might start by investigating how effectively the community utilizes the various energies it is generating or collecting. The investments could then be shifted to the sectors which seem to hold most promise for improvement, and away from those sectors which appear to have reached the point of diminishing returns.

The process of fine tuning the model involves adjusting parameters and the model structure so that its behavior appears reasonable under different circumstances. The preceding examples of runs suggest two areas of the model which could be fine tuned as a result of testing. One I have mentioned is the labor response to cash on hand. In the model this response depends on the current values of cash on hand, compared to average expenditures. It might be reasonable to make it depend on average values of both expenditures and cash on hand. This bit of model adjustment involves the model structure itself, but fine tuning is also possible by varying parameters. Although specific parameter values would not basically alter the actual behavior of a good model, if comparisons are to be made between runs slight variations in values might be important. Thus runs with solar collectors do not appear to be as good as increasing window area because the value for collector efficiency is conservatively low while the absorption-transmission product AT for the windows is somewhat high. While some of the effect of net energy gains is accounted for by the overall U value, the additional losses due to overheating and ventilation are not accounted for. Additional costs of glazing should also be included. Since in the first runs both window area and building size were altered it is not possible to draw any real conclusions about this relationship from those runs but it should be kept in mind as something to be checked.

Actually running the model is very simple. Once it is determined what variations are to be made in the parameters it is possible to make a dozen different runs in as many minutes at a remote computer console, if the results are to be are to be printed offline on a high speed printer. It is also very easy to overlook a parameter that should have been changed but was not, and very frustrating to discover this later when the output is analyzed. If the printout is desired at the console it takes much longer, several minutes for short runs, and the terminal is very loud and uncomfortable but if a mistake has been made,or a parameter overlooked, it is possible to stop the run immediately. What requires the time in the use of the model is establishing exactly what it is desired to analyze in the first place. A good deal of careful thought should be spent on this question and the list of parameters which can be altered should be studied thoroughly (See Appendix: *Using This Model*). Particular attention should be paid to the default values, many of which are set for the size community I wished to investigate (if I had not kept these as default values I would have had to remember to alter many more parameters for each series of runs). The cost of making runs is quite small; depending on the length of run desired each run costs only about one dollar, including printing.

In this paper I have emphasized my belief that agriculture is a necessary component of any totally integrated system. While it is impossible to prove that this is true with this model, the model behavior for systems both with and without agricultural components can be examined to obtain some idea of the relative amounts of labor required to sustain either type of community. While the runs I have previously described indicate that agriculture is a positive investment for a community, and requires less overall labor, because of the favorable (to agriculture) values I chose for crop cash value and wage rate, I did point out that a different choice of values for these parameters could change the picture entirely.

In the final analysis, however, it is up to the potential inhabitants of a community to decide whether, for a given wage rate and crop value, the resulting behavior is desirable. Even if an agricultural community required more labor than one without agricultural components, for some persons the psychological value of agricultural labor would be far superior to work for cash. On the other hand, manual labor may well be anathema to other people, and still others might object to the seasonable aspects of agricultural labor, with its intense peaks of effort at certain times of the year.

The model is naturally limited in its ability to evaluate every possible situation. The national economy, for instance, could affect wages or crop values so that either a more or a less favorable climate for agriculture other than that originally contemplated could occur. Since the parameters are fixed for a given of the model this possibility must be considered when evaluating model behavior. Other issues which must be considered in the process of making a decision as to the desirability of different model behavior are the environmental effects of not investing in certain components. The model does not take into account the effects of pollution, either within the community and caused by an inadequate waste treatment investment, or at a distance, caused by a decision by the community not to grow its own food. Intangibles such as these make the modeller's task in evaluating model behavior doubly or triply difficult.

1 The initial value of $14,000 for DOLAV was intended to approximate one month's expenditures, but otherwise is rather arbitrary. The response of the community to its financial position, discussed elsewhere in this chapter and in Chapter 5, may not be a very realistic representation.

2 The transition period is not always useful in an analysis of system behavior; a model that is formulated to represent steady state conditions may not exhibit reasonable behavior during a transition from the initial conditions to the steady state.

Initial values are assigned to variables for several reasons. Because level equations form part of conservative systems all levels must have an initial value which specifies the amount of whatever is contained. Initial values are also occasionally assigned to auxiliary and rate equations in order to avoid simultanaeous equations when DYNAMO attempts to determine its own initial values for all variables. Initial values can also be used to approximate the steady state value of variables, in order to avoid an extended transition period at the beginning of the model run.

3 The apparent fact that the community only utilized part of its agricultural land was due to an internal modelling error which was corrected for a subsequent series of runs.

5
Summary

SUMMARY

Model Validity and Range of Applicability

A model is only as valid as its usefulness for a given purpose; according to Forrester the concept of validity by itself has no meaning. Instead of attempting to obtain formal "proofs" of model validity he suggests a number of concepts through which to judge the usefulness of a particular model; these are discussed in terms of the community integrated systems model in the following pages (1).

The concept of structural similarity refers to the degree of correspondence that the model has with real life, and to the degree that it is an abstraction of real life. If it is attempted to include every detail, basic relationships may be obscured. On the other hand a model which is too abstract may have limited useful application. While my intention was to maintain a degree of abstraction between these extremes in order to simplify constructing and understanding the model, the model as it now stands is rather inconsistent in its level of detail. Thus parts of the model are fairly abstract, such as some of the investment-capacity relationships and the policies regarding cash labor, while other areas are quite detailed, such as the collection of solar energy. Looking back on the process of constructing the model it seems that if I knew, or felt I knew, enough detail about a particular sector I attempted to include it in the model; if I did not know enough about something I either ignored it or used an arbitrary relationship. Thus some of the investment-capacity tables represent a "best guess," while details such as maintenance labor requirements are left out completely.

Most of these shortcomings are only in changeable parameters, however, a weak point may exist within the cash labor policy. I have mentioned in the description of the agricultural sector that the correlation of various inputs and crop yields was a difficult one to achieve; this turns out to be a peculiar situation which appears to be extremely detailed, yet which involves a high degree of abstraction in the various relationships. Since the model should not be used to predict actual values, but only to analyze the behavior of the system, the inconsistency will probably not be too crucial to the use of the model.

The test of extreme conditions involves utilizing extreme parameter values and observing whether the resultant model behavior is reasonable. One extreme is to put in zero values for all alternative energy components, as well as agriculture. The results of this condition were described in the previous chapter as RUN 1; the only variation in the system was caused by seasonal fluctuations of the heating energy. Cash labor, although fluctuating slightly, maintains a steady state, and all energy expenditures are covered by cash income. The addition of agricultural components introduces seasonal fluctuations to the behavior of cash and agricultural labor, as might be expected. Another extreme condition which I did not examine would be to increase the population well beyond the carrying capacity of the land. Besides problems associated with large populations which were not treated in the model, such as transportation and employment issues, it is probable that with a limited amount of crop area there would be an extreme amount of agricultural labor expended. Since I have been dealing with a small population I have not been concerned with limiting the amount of labor in agriculture but some structure for diverting some labor to cash labor would be necessary with a very large ratio of population to crop area.

As the model evolved from its original concept it has undergone numerous changes, both in basic structural relationships and in details. It is still open to change as relationships come to be better defined and the effects of certain policies are clarified. It is also subject to changes resulting from difficulties which may come out only after prolonged experimentation with the model. At present I can only warn potential users that although most of the components were evaluated individually some were altered when combined, and that there has been incomplete testing of the whole model.

If a model structure is not complete enough, parameter verification may be important, and accurate values of parameters may be necessary for the model to exhibit plausible behavior. The more faithful the model is to real life, the less important it is to have precise parameter values. In previous chapters I have mentioned parameters which may or may not be precise - for many of these it probably is not too critical that they be so, but a user should use precise data if available. For realistic comparisons of components of the model such as solar energy and wind energy, of course, the more precise data is necessary.

The behavior of a model should represent plausible behavior for a real life community. So far it appears that this model behaves plausibly, but since there are no real life counterparts to a totally integrated and self sufficient community it is only a presumption that the behavior of any run beyond the basic non-agricultural and agricultural conditions is in fact plausible. Implicit in the concept of plausibility of behavior is the possibility of being able to determine the direction of change in model behavior brought about by a change in policies in the model. As an example, if agriculture is added to the basic model the seasonal variation in labor is predictable. Likewise, if a methane digester is added to the agricultural model an increase in yields can be expected. I also described in the last chapter the effect of increasing investment in wind generation of electricity; although it was not possible to predict exactly where it would occur, it was safe to predict that at some point the community would begin working and paying more than the extra investment was worth. A model should also exhibit reasonable response to random inputs. In this model the weather introduces randomness; the response to this seasonal input does not appear out of the ordinary.

Forrester characterizes a good model as resembling the family of systems that the particular system modelled belongs to, rather than the specific system. He feels that if a model is too specific extraneous relationships may be included which add nothing to the understanding of relationships within the basic structure. One of my original apprehensions was that this model would be so exclusively agriculturally oriented that it would not be possible to use it for anything else. In testing the model I have found that the elimination of the four agricultural investment values, CIA, CIAM, CIAP, and CIGA, drops agriculture from the picture altogether. Similarly, I had been concerned that the model would turn out to be useful for only a limited range of building variations, but since parameters relating to buildings must be precalculated by the user rather than generated in the model from investments, a wide range of building types, size, and materials can be analyzed. Thus the range of applicability of the model is greater than originally envisioned.

I mentioned earlier that problems could result if the ratio of population to land area was very large. I have not yet determined exactly where this top limit occurs, but the model appears capable of handling very small situations, such as a single family dwelling, although there are probably other models which would be more applicable to that scale. Some of the process efficiencies assumed in the model may be applicable only within the scale for which the model was originally intended; moreover, different processes could become suitable at greatly different scales. Some of these parameters can be altered by the user, but the above mentioned drawbacks of large scales still limit applicability.

In response to a concern that a model be applicable to different community densities, which can have a serious effect on economies of scale, I added the so-called aggregation factors (described in the appendix) to the model to allow the modelling of any number of similar sized components in the solar, wind, and digester sectors. The limitation of the aggregation factor is its assumption that each individual unit behaves in the same manner. The effects of local micro-climates and personal habits, however, may in reality cause significantly different behavior in otherwise similar components. The form of building data input also contributes to the ability to model different densities.

Some aspects of the model do not have upper limits, since the parameters I chose to analyze were relatively small. Thus the choice of a large investment in animals may cause the labor required to care for animals to exceed the total labor available. It is also possible, under certain circumstances, for the amount of labor put into agriculture to greatly exceed not the total amount of labor available, but a reasonable level of labor input per acre. This could occur if the community has an extremely large population combined with an inadequate land base (although in reality a city dweller with a small garden plot might indeed spend an inordinate amount of time on it, compared to any material returns possible).

One of the major difficulties I encountered in constructing the model was in reconciling the delays inherent in the DYNAMO level-rate computation sequence with my understanding of certain processes as involving simultaneous actions. For example, as biogas becomes available from a digester it can either be used immediately or stored. At the same time gas can be used from either the storage or directly from the digester. It was a difficult task to decide on a structure which would allow these possibilities as well as accurately determine the amount of gas wasted due to insufficient storage capacity. Still more complex are the relationships between solar energy collection and storage, which not only has a maximum capacity but also a minimum energy content necessary to provdie useful heat. Add to this two instead of one possible uses, each with different definitions of useful heat and the result is still more complexity. This particular area still has some problems which have not been worked out entirely to my satisfaction at this writing. It is possible that my difficulties may stem from either a misunderstanding of the actual relationships between the different elements in this sector, from a partially unsuccessful attempt to simplify them, or from a misunderstanding of the use of DYNAMO.

I have been discussing the issue of model validity in terms of the ability of the community integrated systems model to simulate the behavior of real systems. Although such simulations could be useful in certain contexts, the true test of validity for this model is its usefulness for its primary purpose of allowing the comparative evaluation of different allocations of investment in alternative energy components.

The previous chapter has shown that because the community is dominated by the seasonality of agriculture (and to a lesser extent, heat losses), the resulting behavior of several different runs using different allocations of investments is very similar. Thus one must look more closely at the values of the outputs to be able to make relative comparisons. This approach may not be entirely accurate, since the objective of DYNAMO is to allow the study of general behavior of systems rather than to make point predictions of system behavior. Of course, it is possible that the comparison of values from different model runs is qualitatively different from the comparison of these values to real systems. In this case it would be reasonable to draw conclusions about different systems based on the relative general trends of their respective behavior, as indicated by the numerical results of the simulations.

At this point I must make a qualified statement as to the usefulness of the model in evaluating alternative integrated systems. While I feel that it is possible to perform this kind of evaluation and to gain insights into system behavior, much more intensive testing of the model, preferably with real data, is necessary to determine how accurate the evaluations are.

Proposals for Further Research

The community integrated systems model has been developed to the stage where it requires fresh insights into the assumptions and structures it incorporates. I feel that I have been saturated with its development and may have acquired irrational attachments to certain aspects of the model which may turn out to be liabilities. It would now be useful for someone with no stake in the model structure itself to use it in an analysis of a real or proposed community, preferably incorporating alternative energies. This would serve at least two purposes as it would permit an independent evaluation of the usefulness and convenience of using the model, in addition to bringing out modelling errors which were not recognized due to the limited scope of my original intentions. If the model as it stands is judged to be too inconvenient for use, despite any success as a tool for analysis, then it cannot be judged to be entirely useful. It may become necessary to provide a better explanation of how to use the model in this case.

As the model is tested and corrected it would also be desirable to explore the possibility of extending its range of useful application. Since some errors in the model may come out only when an evaluation of an extreme condition is attempted, if it is possible to correct the error it may have the effect of extending the range of usefulness.

Although assumptions about the effects of scale were necessary to the construction of the community integrated systems model, it may be possible to further quantify these effects with the aid of the model. There is a certain interplay which could be useful to test assumptions about scale by trying them in the model and evaluating the plausibility of the resulting behavior. The assumptions could be altered until the behavior appeared most plausible, although the distinction between plausible and desired behavior may be difficult to determine.

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Appendix

USING THIS MODEL

The following pages summarize the ways in which the modeller can interact with or alter the basic model. Besides including listings of all values which can be changed and discussing the desirability of any changes, the concept of the modeller as part of the model is presented. The modeller is cautioned to approach this model with a little suspicion; only a great deal of working experience will bring to light all the limitations it places on what can be evaluated. Mechanisms which have been inserted for the convenience of the model maker may not correspond with total accuracy to real world conditions.

Model Parameters

Since the primary objective of the model is to allow the comparison of different allocations of capital investment among the possible natural energy components, the parameters with which the modeller will be most concerned are the different capital investments; these can be easily identified by the letters CI which appear in all of the different investment parameter names. Investment parameters are also starred (*) in Figure 36, a listing of all constants in the model. Also starred are several other parameters which must be entered by the user, primarily building related values; the reasons for not utilzing investment generated values in the building sector are described with that sector in the body of this thesis.

It could be useful for the modeller to take advantage of the ability to evaluate the performance of several smaller components as compared to that of a single larger component. This flexibility is provided by the "aggregation factors" incorporated in the model in the investment-capacity tables. These are identified by the letters NI in the equation name, standing for "number of identical (units)." In making this comparison the extra capital costs of smaller units must be weighed against the potential risks of failure of a single unit; at present, however, the model does not include a mechanism which would allow the direct investigation of the effects of equipment breakdown.

In addition to investment and other critical parameters, Figure 36 lists every other value which is used in the model as a constant and which can be altered by the user. The parameters which are mostly descriptive of the community and which can be freely altered without complications are marked with a circle (o). All of the unmarked parameters represent process relationships and should only be changed after careful investigation; if the modeller disagrees with their value, they can be changed as easily as any other parameter, however. Figure 36 lists the names, a verbal description, the units, and the default value of each parameter. The default value is the value which the model will use unless the modeller has entered a change; with the exception of agricultural investments the default value of all investment parameters is 0, while the default values of other parameters are intended to be reasonable assumptions.

AGRICULTURAL SECTOR

parameter	default value	description and units
o NOPERS	100	number of people
CONSNOR	90 000	normal consumption, kcal/person-month
UAC	360 000	animal feed consumption, kcal/animal-month
RES	12	food reserve, months
UAY	220 000	animal yield, kcal/animal-month

User-Variable Model Constants
Fig. 36

o DPA	1400	unit animal cost, $
* CIAP	22400	investment in animals and pasture, $
HPA	8	unit animal labor reqd, hours/animal-month
KCALH	175	useful energy lf labor, kcal/hour
LABNOR	50	normal agricultural labor, hours/acre
FERNOR	4000	normal fertilizer use, pounds/acre
KCG	32000	energy value of gasoline, kcal/gal
CFG	250	biogas-gasoline conversion, cu ft/gal
FUNOR	10	normal gasoline use, gal/acre
* CIAM	3000	investment in machinery, $
* MCIAM	3000	minimum investment in machinery, $
o DPAC	300	unit cost of crop land, $/acre
* CIA	24000	investment in cropland, $
DAGH	100 000	unit cost of greenhouse, $/acre
* CIGA	25 000	investment in greenhouse, $

CASH-LABOR SECTOR

DCAL	.00025	unit crop value, $/kcal
o WR	3.5	wage rate, $/hour
o AHP	100	average hours per person, hours/person-month
o MP	.00658	unit mortgage cost, $/$-month
o TXINRE	.00583	tax, interest, reserve, etc, $/$-month
DFCAL	.0005	unit cost of food, $/kcal
DKCALF	.00007	unit cost of animal feed, $/kcal
DCF	.0026	unit cost of fuel, $/cu ft
DACR	25	unit crop expenses, seed, etc, $/acre
DPF	.0125	unit cost of fertilizer, $/pound
DKWH	.05	unit electricity cost, $/kwh
DBTU	.000005	unit auxiliary heat cost, $/Btu
PER	12	smoothing period, months
o RESC	0	cash reserve period, months

WASTE-DIGESTER SECTOR

DPM	1	detention period, months
UFR	6	unit feed rate, pounds/cu ft-month
* MDCI	0	investment in digester, $
* NID	1	number of identical digesters
CPM	4	composting period, months
GYLD	8	unit gas yield, cu ft/lb
* GSCI	0	investment in gas storage, $
* NIT	1	number of identical gas tanks
FYAW	1.25	fraction of yield as waste
ECWC	.8	efficiency of crop waste collection

Fig. 36 continued

WPP	8	waste per person, lbs/person-month
WPA	250	waste per animal, lbs/animal-month
FPAF	330	unit hayfield fertilization lbs/acre-month
PHP	.15	process heat required % as decimal
o GCF	100	gas compression factor

SOLAR AND WIND ENERGY SECTOR

* CICOL	0	investment in solar collection, $
* NIC	1	number of identical collectors
o CEFF	.55	average collector efficiency
o UT	.04	storage tank thermal conductivity, Btu/hr-sqft-°F
* CISTO	0	investment in solar storage, $
* NIS	1	number of identical storage tanks
DTEM	75	range of useful temperatures, °F
DTHT	40	range of threshold temperature, °F
CP	8.34	unit thermal capacity of water, Btu/gal-°F
GALCF	7.48	gallon-cu ft conversion for water
* CIWG	0	investment in wind generator, $
o NIW	1	number of identical wind generators

BUILDING ENERGY FLOW SECTOR

* AWIN	0	area of south windows, sq ft
AT	.8	average product of transmissivity and absorptivity for windows
* CIBLDG	0	capital investment in buildings, $
o TUVAL	.15	overall U value for above ground part of building, Btu/hr-sqft-°F
o TUVBG	.07	overall U value for below ground part of building, Btu/hr-sqft-°F
* BAREA	0	surface area of building above ground, sq ft
* BGAREA	0	surface area of building below ground, sq ft
o TIN	65	inside temperature, °F
TDEV	8	deviation of temperatures from monthly means, °F
IWT	50	inlet water temperature, °F
o GPP	300	unit hot water use, gal/person-month
o ELUS	75	unit electricity use, kwh/person-month
o GHRS	16	hours of generator operation, hours/month
* CIELG	0	investment in gas-electric generator, $
CFK	21	biogas-electricity conversion, cu ft/kwh
o CEP	292,000	unit cooking energy requirement, Btu/person-month
WSF	.5	wood stove efficiency, $ as decimal

Fig. 36 continued

	BTUC	18,000,000	energy value of wood, Btu/cord
	BTUF	600	energy value of biogas, Btu/cu ft
	WD	1	wood delay time, months
*	CIW	0	capital invested in woodlot, $
o	DAW	200	unit cost of woodland, $/acre
	CA	.1	unit growth rate of wood, cords/acre-month
o	HPC	8	labor required for woodcutting, hours/cord

Fig. 36 continued

Unless the modeller is simply using the model as an exercise the tabular input which relates model processes to a specific site and climate must also be provided. Weather data (fig 8) make up the bulk of this category; the tables, their inputs and outputs, and a verbal description are listed in Fig 37. Note that all of the tables in this category have the month of the year as input; the appropriate information can be obtained from climatic atlases or weather summaries, plotted by months, and entered in the appropriate tables in reruns. If these values are not altered, data for a point midway between Portland and Augusta, Maine, will be used by the model.

output/name	input	description
NORSUN/SUNT	MONTH	mean percentage of possible sunshine
MXSRAD/SRADT	MONTH	maximum clear day sun on south wall Btu/sq ft
MXCOL/COLT	MONTH	maximum clear day sun on 60° collector, Btu/sq ft
AVW/VWT	MONTH	monthly wind speed, mph
TOU/TOUT	MONTH	average outside temperature, °F
TG/TGT	MONTH	average ground temperature, °F
EFWC/EFWCT	MONTH	efficiency of animal waste collection
TOTAR/TOTART	MONTH	seasonal area limitations, acres

Climate or Site Specific Relationships
Fig. 37

Another category of tabular input relates investments in alternative energy components to the size or capacity of those components (Fig 38). These relationships should not be altered by the user unless a careful investigation of economies of scale is undertaken, or unless accurate cost information is available for a wide range of sizes.

output/name	input	description
ACOL/ACOLT	ACOL	collector area, sq ft
SCAP/SCAPT	ASTO	storage size, gallons
NOMGEN/NOMT	CIWG	nominal generator rating, kwe
MDCAP/MDCAPT	MDCI	digester capacity, cu ft
GSTC/GST	SCI	gas holder capacity, cu ft

Investment-Capacity Relationships
Fig. 38

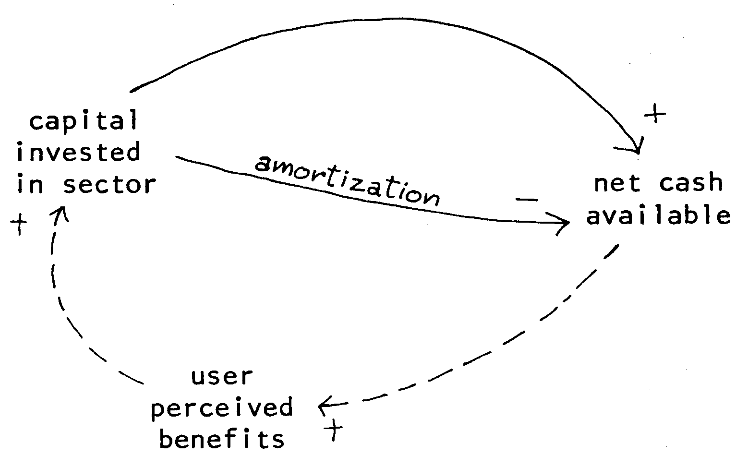
The third and final category of tabular input is much more subjective in interpretation; these are the process and policy relationships (Fig 39). Some relationships, particularly those dealing with crop yields, should be altered only with the same precautions as described for the investment-capacity relationships, but other inputs, such as consumption rates and cash recovery time can be changed to suit the social makeup of the community.

output/name	input	description
KWHPK/KWHT	VW	unit monthly wind generator output, kwh/kwe-month
FWC/FWCT	WAV	fraction of waste composted
CONSM/CONSMT	FOODAV/FOODNOR	food consumption multiplier
ALAM/ALAMT	(area comparison)	labor multiplier from area
LFM/LFMT	GPA	labor multiplier from fuel use
YFM/YFMT	FERUR/ARIN	yield multiplier from fertilizer
FERF/FERFT	FERUR/FERURD	fertilizer modifier from previous fertilizer application
EFM/EFMT	GPA	fuel effectiveness
FDM/FDMT	DR	fuel use modifier from cash
RT/RTT	DR	cash recovery time months

Process and Policy Relationships
Fig. 39

The Modeller as Part of the Model

Because the model is intended to be a tool, there are some feedback relationships which exist outside the boundaries of the computer model itself. These have to do with the user perceived benefits of a particular allocation of capital investment. The primary outputs open to user interpretation are the amounts of money and labor necessary for the system to sustain itself. To aid in determining the relative contribution of each alternative investment allocation and to make it possible to make changes in investment allocation on some rational basis, the net cash-labor flows from each sector can also be made available as output. These may be interpreted somewhat as returns on investment. The user may attempt to increase a perceived benefit by increasing investment in that sector, but at the same time additional amortization costs will tend to decrease the desired benefit (Fig 36). While an equilibrium may be found at some point for a particular sector, it may not correspond with the equilibrium for the entire integrated system.



Causal Loop Diagram Illustrating Feedback Through Model User
Fig. 36

Model Specifications

Because the model uses weather input and has an agricultural basis, length of runs of less than one year are not very meaningful, except for testing computations. In order to determine the reliability of either the model or the community structure proposed, it is necessary to make runs of at least several years duration. The computation interval DT must be chosen to be less than the smallest period of interest in the model. If one month is a sufficiently detailed period of interest and allows enough detail of the yearly cycles for evaluation, then one week would be a reasonable computation interval. DT should also be less than 1/2 the length of any first order delays and 1/6 the length of any 3rd order delays in the model.

Since the model is rather abstract, printed data output is not always useful; it is the general relationship between cash and labor requirements which is of most interest to the modeller. This can be plotted on a monthly basis for the duration of the model run while the printed data can be limited to every three or four months, just to provide a reference to the plots.

DYNAMO Flow Diagram Symbols

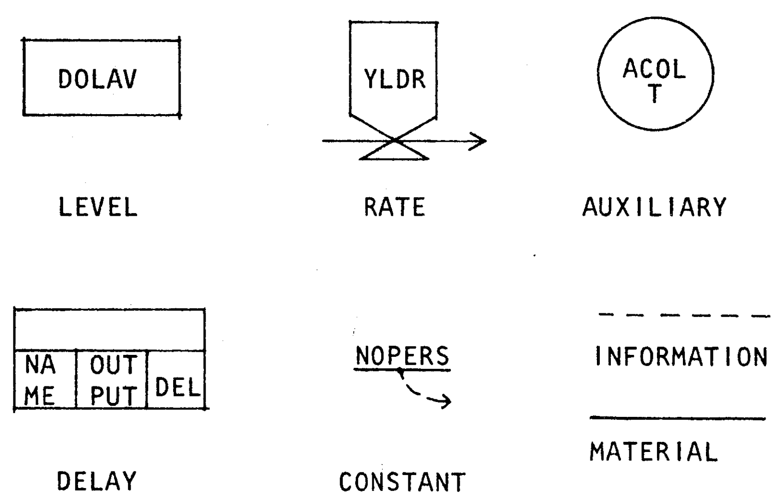
Flow diagrams are used in the development of a model to help understand the relationships between the various equations. A completed flow diagram makes it easy for a model user to see which variables are related. The symbols illustrated below are used for the flow diagrams in this paper.

Level equations, depicted as rectangles, represent the state of the system at a given point in time, while rate equations, shown as valves, represent the actions in the system. Auxiliary equations are used to relate the state of the system to the rates and to provide output for the model user; these are represented by circles. Auxiliary equations involving tables are also identified by an extra T in the circle. Rates originating from outside the system or which flow out of it are indicated by arrows beginning or ending in mid-air; although some diagrams conventionally use an irregular shape for sources or sinks I have not done so.

Delays, which are special functions in DYNAMO, are represented by a partitioned rectangle. Although I show a sixth order delay in the diagram for the agricultural sector such a delay does not exist as a separate function in DYNAMO; I chose this representation in order to keep the diagram less cluttered.

Lines indicate relationships between variables. Between levels and rates there are always solid lines, indicating material flow. Dashed lines represent information flow and are drawn to a variable from every variable that appears in its equation.

Constants are indicated by an underline. A heavy line is used to indicate information the user should provide; this is used primarily for the constants but occasionally in an auxiliary equation for tabular data input.



```
*         THE MAGNIFICENT COMMUNITY INTEGRATED SYSTEM MODEL                  00000004
*                            SOLAR ENERGY SECTOR                             00000005
        SOLAR ENERGY AVAILABLE                                               00000006
A   PERSUN.K=NORMRN(NORSUN.K,SNDV.K)*.01    CURRENT % OF POSS SUN            00000010
A   NORSUN.K=TABLE(SUNT,MONTH.K,0,12,0.5)  MEAN % OF POSS SUN                00000012
T   SUNT=46/50/56/60/56/51/51/52/52/52/54/59/61/62/60/56/55/55/              00000013
X   55/56/49/41/42/44/46          AT 44 DEG N  71 DEG W                      00000014
A   SNDV.K=FIFGE((100-NORSUN.K)/2.4,NORSUN.K/2.4,NORSUN.K,50)                00000015
A   MXSPAD.K=TABLE(SRADT,MONTH.K,0,12,0.5)    MAX CLEAR DAY SUN ON S WALL 00000040
T   SRADT=1480/1570/1660/1720/1700/1620/1450/1250/1060/920/810/              00000041
X   760/740/800/880/1000/1170/1380/1550/1630/1640/1610/1560/1490/1480        00000042
                                BTU/SQ FT/DAY AT 44 DEG N                    00000043
A   MXCOL.K=TABLE(COLT,MONTH.K,0,12,0.5)    MAX DAILY SUN ON 60DEG COL       00000044
T   COLT=1570/1690/1850/2010/2160/2190/2150/2080/2000/1920/1850/1810/180000000045
X   /1830/1880/1940/2010/2060/2060/2020/1930/1780/1640/1570/1570             00000046
                            BTU/SQFT-DAY AT 44DEG N LAT                      00000047
A   SGAIN.K=PERSUN.K*MXSRAD.K         DAILY INCIDENCE ON S WALL (BTU/SQFT)00000060
                                                                             00000061
                         SOLAR STORAGE                                       00000062
L   SOLAV.K=SOLAV.J+DT*(SCOLR.JK-SUSER.JK-SLOSSR.JK)                         00000070
                               ENERGY IN SOLAR STORAGE,  BTU                 00000071
N   SOLAV=SOLA                                                               00000072
C   SOLA=0                                                                   00000073
                         SOLAR COLLECTION                                    00000074
R   SCOLR.KL=SCOLRI.K                                                        00000080
A   SCOLRI.K=SCOL.K*ACOL*(730/24) SOLAR ENERGY COLLECTION (BTU/MO)           00000082
N   ACOL=TABXT(ACOLT,CICOL/NIC,0,60000,10000)*NIC  COLLECTOR AREA (SQFT)  00000083
T   ACOLT=0/500/1333/2143/3077/4167/5000 SQFT                                00000084
C   CICOL=0 $          CAPITAL INVESTED IN SOLAR COLLECTOR                   00000085
C   NIC=1           NUMBER OF IDENTICAL COLLECTORS                           00000086
A   SCOL.K=PERSUN.K*MXCOL.K*CEFF        BTU/SQ FT-DAY                        00000090
C   CEFF=.55    AVERAGE COLLECTOR EFFICIENCY                                 00000091
                                                                             00000092
                         SOLAR ENERGY USE                                    00000093
R   SUSER.KL=SSH.K+SHW.K     SOLAR ENERGY USE ,  BTU/MONTH                   00000100
A   SSH.K=MIN(NSAV.K,BHREQ.K)       SOLAR SPACE HEATING (BTU/MO)             00000110
```

COMPLETE MODEL LISTING

Caution: some eqn errors as listed — errata sheet to come. CH 25 Nov 77

```
A   NSAV.K=SAVC.K+(SOLAV.K/DT)-(SOLAV.K/STCM)-(SMIN/DT)                    00000120
                     NET SOLAR AVAILABLE FOR SPACE HEATING (BTU/MO)        00000121
A   SAVC.K=SAD.K+STS.K          SOLAR AVAILABLE FROM COLLECTION            00000123
A   SAD.K=MIN(SCOLRI.K,BHREQ.K/3)   SOLAR AVAILABLE DIRECTLY               00000124
A   STS.K=MIN(SCOLRI.K-SAD.K,(SHCAP-SOLAV.K)/DT)   SOLAR TEMP STORED       00000125
R   SLOSSR.KL=MAX(SCOLRI.K+(SOLAV.K/DT)-SSH.K-SHW.K-SHCAP,(SOLAV.K/STCM))00000170
                      SOLAR ENERGY LOSSES                                  00000171
N   STCM=(10.4/UT)*EXP((1/3)*LOGN(MAX(SCAP/GALCF,1E-6)))/730              00000172
                              STORAGE THERMAL TIME CONSTANT                00000173
C   UT=.04 BTU/HR-SQFT-DEG(F)  TANK THERMAL CONDUCTIVITY                   00000174
C   CISTO=0 $                 CAPITAL INVESTED IN STORAGE                  00000175
C   NIS=1    NUMBER OF IDENTICAL STORAGE TANKS                             00000176
N   SHCAP=SCAP*CP*(DTEM+DTHT)*NIS      HEAT CAPACITY OF STORAGE,  BTU      00000177
N   SMIN=SCAP*CP*DTHT*NIS  THRESHOLD VALUE OF USEFUL SOLAR ENERGY          00000178
N   SCAP=TABXT(SCAPT,CISTO/NIS,0,8000,2000) UNIT STORAGE VOLUME            00000179
T   SCAPT=0/7480/22960/55920/74800 GALLONS                                 00000181
C   DTEM=75 DEG(F)                      RANGE OF USEFUL TEMPERATURES       00000182
C   DTHT=40 DEG(F)   RANGE OF THRESHOLD TEMPERATURE                        00000183
C   CP=8.34 BTU/GAL-DEG(F)                                                 00000184
C   GALCF=7.48 GAL/CUFT                                                    00000185
A   TT.K=((NSAV.K-SSH.K)/(SCAP*CP*NIS+1))+55 TANK TEMP AFTER SPACE HEAT    00000190
                                                                           00000191
                                                                           00000192
                                                                           00000193
*               WIND ENERGY                                                00000194
A   VW.K=NORMRN(AVW.K,VDEV.K) CURRENT AVERAGE WIND SPEED (MPH)             00000200
A   AVW.K=TABLE(VWT,MONTH.K,0,12,1)   MONTHLY WIND SPEED (MPH)             00000202
T   VWT=12/11.5/11.5/10.5/9.5/8/8/7.5/8/10/10.5/11/10 MILES/HOUR           00000203
                     (AVERAGE OF PORTLAND AND EASTPORT)                    00000204
A   VDEV.K=(AVW.K+3)/2.4    DEVIATION OF WIND FROM NORMAL                  00000205
A   KWHPK.K=TABHL(KWHT,VW.K,2.5,25,2.5) UNIT  MONTHLY OUTPUT (KWH/MO-KWE)00000230
T   KWHT=0/16/45/83/145/210/280/355/410/445 KWH/MO-KWE                     00000231
A   WGENR.K=KWHPK.K*NOMGEN*NIW     ELECTRICITY GENERATED, KWH/MO           00000240
N   NOMGEN=TABXT(NOMT,CIWG/NIW,0,52000,4000) NOMINAL GENERATOR RATING      00000241
T   NOMT=0/2/7/13.3/19.9/26.4/32.9/39.5/46.1/52.8/59.3/66.5/73/79 KWE      00000242
C   CIWG=0 $          CAPITAL INVESTMENT IN WIND PLANT                     00000243
```

```
C   NIW=1           NUMBER OF IDENTICAL WIND GENERATORS                        00000244
                                                                               00000245
*                         BUILDING ENERGY FLOW SECTOR                          00000246
                                                                               00000247
                          SPACE HEATING                                        00000248
A   BHREQ.K=MAX(FIFGE(BLOSS.K-BSGAIN.K,0,TIN,TO.K+5),0)                        00000250
                          BUILDING HEAT REQD (BTU/MO)                          00000251
A   BSGAIN.K=SGAIN.K*AWIN*AT*730/24  BUILDING SOLAR GAIN (BTU/MO)              00000260
C   AWIN=0 SQFT             AREA OF SOUTH WINDOWS                              00000261
C   AT=.8                   AVERAGE ALPHA-TAU PRODUCT                          00000262
C   CIBLDG=0 $              INVESTMENT IN BUILDINGS                            00000263
A   BLOSS.K=(TUVAL*BAREA*(TIN-TO.K)+TUVBG*BGAREA*(TIN-TG.K))*INFIL*730         00000270
                             BUILDING HEAT LOSS,  BTU/MONTH                    00000271
C   TUVAL=.15 BTU/HR-SQFT-DEG(F)  NET U-VALUE FOR BUILDING, INCL WINDOWS       00000272
C   TUVBG=.07 BTU/HR-      NET U-VALUE FOR BELOW GROUND PORTION OF BLDG        00000273
C   BAREA=0 SQFT                SURFACE AREA ABOVE GROUND                      00000274
C   BGAREA=0 SQFT               SURFACE AREA BELOW GROUND                      00000275
C   TIN=65 DEG(F)               INSIDE AIR TEMPERATURE                         00000276
C   INFIL=1.3               INFILTRATION FACTOR                                00000277
                                                                               00000278
                       TEMPERATURES                                            00000279
A   TO.K=NORMRN(TOU.K,TDEV)        AVERAGE OUTSIDE TEMPERATURE                 00000280
A   TOU.K=TABLE(TOUT,MONTH.K,0,12,0.5)  MONTHLY MEAN OUTSIDE TEMPERATURE       00000281
T   TOUT=20/18/19/21/27/31/36/41/48/55/59/62/67/70/70/66/63/60/53/47/41/       00000282
X   36/29/23/20 DEG(F)                                                         00000283
C   TDEV=8 DEG(F)                                                              00000284
A   TG.K=TABLE(TGT,MONTH.K,0,12,0.5)       GROUND TEMPERATURE                  00000300
T   TGT=38.5/37/36/35/34/34/35/38/42.5/47.5/53/58/62/63.5/64.5/64/             00000301
X   63/62/60.5/58/54/50/47/43.5/40.5 DEG(F)                                    00000302
A   AUXRQ.K=BHREQ.K-SSH.K  AUXILIARY HEAT REQD (BTU/MO)                        00000310
                                                                               00000311
                        HOT WATER                                              00000312
A   SHW.K=MIN((MIN(120,TT.K)-IWT)*HWC,NSAV.K-SSH.K)  HW FROM STORAGE           00000320
C   IWT=50 DEG(F)              INLET WATER TEMP                                00000321
N   HWC=NOPERS*GPP*CP   HW THERMAL CAPY PER DEG(F) HEATING REQD                00000322
C   GPP=300 GAL/PERS-MO                                                        00000323
```

```
A   HWERQ.K=MAX(HWC*(120-TT.K),0)   HW AUXILIARY HEAT REQD (BTU/MO)        00000330
                                                                            00000331
                     ELECTRICITY                                            00000332
A   NELRQ.K=ELRQ-WGENR.K-GENR.K     NET ELEC PURCHASES (SALES) (KWH/MO)    00000340
N   ELRQ=NOPERS*ELUS            ELECTRICITY REQD (KWH/MO)                   00000341
C   ELUS=75 KWH/PERS-MO                                                     00000342
A   GENR.K=MIN(MIN(EAG.K,MXGEN),GELD.K)    ELECT FROM BIOGAS (KWH/MO)       00000350
N   MXGEN=CELG*(730/24)*GHRS      MAX GEN POSS  (KWH/MO)                    00000351
C   GHRS=16 HRS/DAY             HOURS OF GEN OPERATION                      00000352
N   CELG=CIELG/UGC              GENERATOR RATING (KWE)                      00000353
C   UGC=200 $/KWE                                                           00000354
C   CIELG=0 $                   INVESTMENT IN GAS ELECTRICAL GENERATOR      00000355
A   GELD.K=MAX(ELRQ-WGENR.K,0)  ELECTRICITY DESIRED FROM GAS (KWH/MO)       00000360
A   EAG.K=(GUP.K-GUF.K)/CFK   MAX ELECT POSS FROM GAS                       00000370
C   CFK=21 CUFT/KWH             BIOGAS-ELECTRICITY CONVERSION (25%)         00000371
                                                                            00000372
                     COOKING                                                00000373
A   CFPUR.K=TCD-WUSE.K-GEUS.K      COOKING FUEL PURCHASES (BTU/MO)          00000380
N   TCD=NOPERS*CEP               TOTAL COOKING ENERGY DEMAND (BTU/MO)       00000381
C   CEP=2.92E5 BTU/PERS-MO                                                  00000382
A   WUSE.K=MIN(WOODE.K,TCD)     ENERGY FROM WOOD (BTU/MO)                   00000390
A   WOODE.K=WOODAV.K*BTUC*WSF/DT  WOOD ENERGY AVAILABLE (BTU/MO)            00000392
C   WSF=.5           WOOD STOVE EFFICIENCY                                  00000393
C   BTUC=18E6 BTU/CORD                                                      00000394
A   GEUS.K=MIN(TCD-WUSE.K,GEAC.K)   ENERGY FROM GAS (BTU/MO)                00000410
A   GEAC.K=((EAG.K*CFK)-GUE.K)*BTUF*.8      GAS ENERGY AVAILABLE (BTU/MO)  00000412
C   BTUF=600 BTU/CUFT                                                       00000413
                                                                            00000422
                     WOOD ENERGY                                            00000423
L   WOODAV.K=WOODAV.J+DT*(WCTR.JK-WUR.JK)    WOOD AVAILABLE (CORDS)         00000430
N   WOODAV=WOOD                                                             00000431
C   WOOD=0                                                                  00000432
R   WUR.KL=WUSE.K/(BTUC*WSF)      WOOD USE RATE (CORDS/MO)                  00000440
R   WCTR.KL=DELAY3(WCUTR.JK,WD)     RATE OF WOOD AVAILABILITY (CORDS/MO)    00000450
R   WCUTR.KL=LABW.K/HPC                                                     00000452
C   WD=1 MONTHS      WOOD DELAY TIME                                        00000453
```

```
                                                                        00000461
A  MWCP.K=MIN(WGR,CWN)     MAX WOOD CUTTING POSS (CORDS/MO)            00000470
N  WGR=ACW*CA            WOOD GROWTH (CORDS/MO)                         00000471
N  ACW=CIW/DAW             WOODLOT SIZE (ACRES)                         00000472
C  CIW=0 $               CAPITAL INVESTED IN WOODLOT                     00000473
C  DAW=200 $/ACRE                                                       00000474
C  CA=.1 CORDS/ACRE-MO                                                  00000475
N  CWN=TCD/(BTUC*WSF)      WOOD NEEDED FOR COOKING (CORDS/MO)           00000476
A  LABW.K=MIN(LAVW.K,MWCP.K*HPC)  WOODCUTTING LABOR (HRS/MO)            00000480
A  LAVW.K=LAVAG.K-LABAG.K     LABOR AVAILABLE FOR WOODCUTTING (HRS/MO)  00000482
C  HPC=8 HRS/CORD                                                       00000483
                                                                        00000491
*              WASTE/BIOGAS-FERTILIZER SECTOR                           00000492
                                                                        00000493
                        FERTILIZER                                      00000494
L  FERAV.K=FERAV.J+DT*(FPR.JK+CR.JK+FERPUR.JK-FERUR.JK-FERHF.J)        00000500
                                    TOTAL FERTILIZER USE (LBS/MO)       00000501
N  FFRAV=FER                                                            00000502
C  FER=0 LBS                                                            00000503
A  FERHF.K=MIN(FERAV.K/DT,FERHFD)       FERTILIZER USED ON HAYFIELDS    00000510
N  FERHFD=NOAN*FPAF                     FERT DESIRED FOR HAYFIELDS      00000511
C  FPAF=330 LBS/ACRE                                                    00000512
R  FPR.KL=DELAY1(DFRF.JK,DPM)  FERTILIZER PRODUCED IN DIGESTER, LBS/MO  00000520
C  DPM=1 MONTH DETENTION PERIOD                                         00000521
R  DFRF.KL=DFR.K  DIGESTER LOADING IN TERMS OF FERTILIZER, LBS/MO       00000530
A  DFR.K=MIN(MXCP,WAV.K/DT)                                             00000532
                WASTE  DIGESTED (LBS/MO)                                00000533
N  MXCP=MDCAP*UFR*NID       MAXIMUM DIGESTER LOADING, LBS/MO            00000534
C  UFR=6 LBS/CUFT-MO                  UNIT LOADING RATE                 00000535
N  MDCAP=TABXT(MDCAPT,MDCI/NID,0,8000,2000)  DIGESTER CAPACITY          00000536
T  MDCAPT=0/1000/3000/6000/10000 CUFT                                   00000537
C  MDCI=0 $ CAPITAL INVESTED IN BIOGAS PLANT                            00000538
C  NID=1                 NUMBER OF IDENTICAL DIGESTERS                  00000539
R  CR.KL=DELAY1(WCR.JK,CPM)  FERTILIZER PRODUCED FROM COMPOST, LBS/MO   00000550
C  CPM=4 MONTHS COMPOSTING PERIOD                                       00000551
                                                                        00000552
```

```
            GAS                                                                 00000553
L  GASAV.K=GASAV.J+DT*(GPR.JK-PHR.JK-GUR.JK-GWR.JK)  GAS AVAILABLE, CUFT00000560
N  GASAV=GAS                                                                    00000561
C  GAS=0 CUFT                                                                   00000562
R  PHR.KL=GPRI.K*PHP                  PROCESS HEAT (CUFT/MO)                    00000570
C  PHP=.15              PERCENT OF OUTPUT FOR HEAT                              00000571
R  GPR.KL=GPRI.K  GAS PRODUCTION, CUFT/MO                                       00000580
A  GPRI.K=DELAY1(DFPG.JK,DPM) GAS PRODUCTION INDICATED                          00000582
R  DFRG.KL=DFR.K*GYLD  DIGESTER LOADING IN TERMS OF GAS, CU FT/MO               00000600
C  GYLD=8 CUFT/LB                GAS YIELD PER LB DRY SOLIDS                    00000601
R  GWR.KL=MAX((GPRI.K*(1-PHP))+(GASAV.K/DT)-GURI.K-(GSTC*GCF)/DT,0)             00000610
                                    GAS WASTED (CUFT/MO)                        00000611
N  GSTC=TABXT(GST,GSCI/NIT,0,2500,500)*NIT   STORAGE TANK  SIZE                 00000612
I  GST=0/270/1000/3200/6680/10960 CUFT                                          00000613
C  GSCI=0 $                            INVESTMENT IN STORAGE TANK               00000614
C  GCF=100   GAS COMPRESSION FACTOR(1500 PSI)                                   00000615
C  NIT=1          NUMBER OF IDENTICAL TANKS                                     00000616
R  GUR.KL=GURI.K                    GAS USE (CUFT/MO)                           00000620
A  GURI.K=GUF.K+GUE.K+GUC.K                                                     00000622
A  GUF.K=FUS.K*CFG                GAS USED FOR FUEL (CUFT/MO)                   00000623
A  GUE.K=GENR.K*CFK               GAS USED FOR ELECTRICITY (CUFT/MO)            00000624
A  GUC.K=GEUS.K/(BTUF*.8)         GAS USED FOR COOKING (CUFT/MO)                00000625
                                                                                00000661
A  GUP.K=(GPRI.K*(1-PHP))+(GASAV.K/DT)     GAS USE POSSIBLE (CUFT/MO)           00000670
                                                                                00000671
             WASTE                                                              00000672
R  CWP.KL=YLDR.JK*FYAW*ECWC/1800   CROP WASTE PRODUCTION, LBS/MO                00000680
C  FYAW=1.25 FRACTION OF YIELD AS WASTE                                         00000681
C  ECWC=.8      EFFICIENCY OF CROP WASTE COLLECTION                             00000682
R  WDR.KL=DFR.K            WASTE USE IN DIGESTER                                00000690
A  FWC.K=TABHL(FWCT,(WAV.K/DT)/(MXCP+1E-6),1,3,0.5) FRACTION COMPOSTED          00000700
T  FWCT=0/.33/0.5/0.61/0.7                                                      00000701
L  WAV.K=WAV.J+DT*(AWP.JK+CWP.JK-WDR.JK-WCR.JK) DRY WASTE AVAILABLE LBS         00000710
N  WAV=WA                                                                       00000711
C  WA=0                                                                         00000712
R  AWP.KL=(NOPERS*WPP)+(NOAN*WPA*EFWC.K) ANIMAL WASTE PRODUCED, LBS             00000720
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C   WPP=7      LBS/MO TOTAL SOLIDS,                                                    00000721
C   WPA=250       LBS/MO      WASTE PER ANIMAL UNIT                                    00000722
A   EFWC.K=TABLE(EFWCT,MONTH.K,0,12,1)*.01                                             00000730
              EFFICIENCY OF ANIMAL WASTE COLLECTION                                    00000731
T   EFWCT=90/90/90/90/75/65/65/65/65/65/75/90/90                                       00000732
R   WCR.KL=WCRI.K                                                                      00000750
A   WCRI.K=(WAV.K-(DFR.K*DT))*EFWC.K  DRY WASTE COMPOSTED                              00000752
A   LABMD.K=DFR.K*HLD            DIGESTER LABOR                                        00000760
N   HLD=FIFGE(.0025,.0015,CIELG,0)   UNIT RATE OF DIGESTER LABOR (HRS/LB)00000761
A   LABCM.K=MIN(LAVCM.K,WCRI.K*HLC)        COMPOSTING LABOR (HRS/MO)                   00000780
A   LAVCM.K=LAVW.K-LABW.K     LABOR AVAIL FOR COMPOSTING (HRS/MO)                      00000782
N   HLC=FIFGE(.0002,.002,CIAM,1500)   UNIT RATE OF COMPOST LABOR (HRS/LB)00000783
                                                                                       00000786
*                  AGRICULTURAL SECTOR                                                 00000787
                                                                                       00000788
                 FOOD                                                                  00000789
L   FOODAV.K=FOODAV.J+DT*(YLDR.JK+ANYLD-CONSR.JK-SALESR.JK)                            00000790
                                        FOOD AVAILABLE (KCAL)                          00000791
N   FOODAV=FA                                                                          00000792
C   FA=1080000                                                                         00000793
R   CONSR.KL=CONSI.K+ACONSI.K        FOOD CONSUMPTION (KCAL/MO)                        00000800
A   CONSI.K=MIN(FOODAV.K/DT,FOODNOR*CONSM.K) HUMAN CONSUMPTION                         00000802
N   FOODNOR=NOPERS*CONSNOR     NORMAL FOOD CONSUMPTION (KCAL/MO)                       00000803
C   NOPERS=100 PEOPLE                                                                  00000804
C   CONSNOR=90000 KCAL/PERS-MO   UNIT FOOD CONSUMPTION                                 00000805
A   CONSM.K=TABHL(CONSMT,FOODAV.K/FOODNOR,0,12,3)  CONSUMPTION MULTIPLIER00000820
T   CONSMT=0.667/1/1.1/1.4/1.5                                                         00000821
A   ACONSI.K=MIN((FOODAV.K/DT)-CONSI.K,ACONS)   ANIMAL CONS FROM AV FOOD 00000830
N   ACONS=NOAN*UAC                                                                     00000831
C   UAC=360000 KCAL/AN-MO                                                              00000832
A   PURAN.K=ACONS-ACONSI.K       FEED PURCHASED (KCAL/MO)                              00000833
A   PURF.K=FIFGE(0,FOODNOR*0.75-FOODAV.K/DT,FOODAV.K/DT,FOODNOR*0.75)                  00000840
X    +(.1*FOODNOR)            FOOD PURCHASED (KCAL/MO)                                 00000841
R   SALESR.KL=MAX(0,FOODAV.K-FOODRES-CONSI.K*DT-ACONSI.K*DT)  FOOD SALES 00000860
N   FOODRES=FOODNOR*RFS      FOOD RESERVE (KCAL)                                       00000861
C   RFS=12 MONTHS                                                                      00000862
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S   TCONS.K=CONSI.K+PURF.K      TOTAL HUMAN CONSUMPTION (KCAL/MO)           00000865
                                                                            00000868
                     YIELD - ANIMALS                                        00000869
N   ANYID=NOAN*UAY              FOOD FROM ANIMALS (KCAL/MO)                 00000870
C   UAY=220000 KCAL/AN-MO                                                   00000871
N   NOAN=CIAP/DPA               NUMBER OF ANIMALS                           00000872
C   DPA=1400 $/ANIMAL                                                       00000873
C   CIAP=22400 $       INVESTMENT IN ANIMALS AND PASTURE                    00000874
N   LABAN=NOAN*HPA            LABOR REQUIRED FOR ANIMAL CARE  (HRS/MO)      00000875
C   HPA=8 HRS/AN-MO                                                         00000876
                                                                            00000881
                     YIELD - CROPS                                          00000882
R   YLDR.KL=(YLB.K+YFL.K)*YFM.K       CROP YIELD (KCAL/MO)                  00000890
N   YLDR=200000                                                             00000891
A   YLB.K=DLINF3(YLB1.K,1.5)      CROP YIELD FROM LABOR                     00000895
A   YFL.K=DLINF3(YFL1.K,1.5)          YIELD FROM FUEL                       00000896
A   YFM.K=TABHL(YFMT,YFM2.K,0,12000,1000) YIELD MULT FROM FERTILIZER        00000897
T   YFMT=1/3.25/4.7/5.6/6.2/6.7/7.1/7.5/7.75/8.1/8.35/8.6/8.75              00000898
                                                                            00000922
                     AGRICULTURAL LABOR                                     00000923
A   YLB1.K=DLINF3(LABR.JK*KCALH*10,1.5)                                     00000930
C   KCALH=175 KCAL/HR         USEFUL ENERGY OF LABOR                        00000931
R   LABR.KL=LABAG.K                  AGRICULTURAL LABOR (HRS/MO)            00000940
A   LABAG.K=MIN(LAVAG.K,((LABNOR*ARI.K)+(ALABN*AREA.K))*LAM.K*LFM.K)        00000942
A   LAVAG.K=LABAV-LABMD.K-LABAN LABOR AVAILABLE FOR AGRICULTURE (HRS/MO)    00000943
C   LABNOR=26 HRS/ACRE                                                      00000944
C   ALABN=8                                                                 00000945
A   LAM.K=FIFGE(2.5,ALAM.K,GHA,TOTAR.K)  LABOR MULTIPLIER FROM AREA         00000970
A   ALAM.K=TABHL(ALAMT,((ARI.K/DT)*(12-MONTH.K))/(ARDES.K+1E-6),0,1,0.2)    00000972
T   ALAMT=5/3/2/1.4/1.2/1                                                   00000973
A   LFM.K=TABHL(LFMT,GPA.K,0,10,2.5)  LABOR MULTIPLIER FROM FUEL USE        00000990
T   LFMT=11/6.7/4/2.2/1                                                     00000991
                                                                            00000992
                                                                            00000993
                     FERTILIZER INPUTS                                      00000994
A   YFM2.K=DLINF3(YFM1.K,1.5)                                               00001000
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A   YFM1.K=DLINF3(FERUR.JK/(ARIN.JK+1E-2),1.5)                              00001002
R   FERUR.KL=MIN(FERUD.K,(FERAV.K/DT)-FERHF.K) FERTILIZER USE FOR CROPS     00001020
N   FERUR=0                                                                 00001021
R   FERURD.KL=FERUD.K                                                       00001030
N   FERURD=12000                                                            00001031
A   FERUD.K=FERNOR*FERMOD.K*ARI.K     FERTILIZER USE DESIRED (LBS/MO)       00001033
C   FERNOR=4000 LB/ACRE                                                     00001034
A   FERMOD.K=MIN(FERA.K*FERF.K,3)  FERTILIZER USE MODIFIER                  00001050
A   FERA.K=FIFGE(3,1,GHA,TOTAR.K)  MODIFIER FROM AREA LIMITATIONS           00001052
A   FERF.K=TABHL(FERFT,FERUR.JK/(FERURD.JK+1E-6),0,1,.25)                   00001053
            MODIFIER FROM PREVIOUS APPLICATIONS                             00001054
T   FERFT=3/2/1.5/1.2/1                                                     00001055
R   FERPUR.KL=FERURD.JK-FERUR.JK     FERTILIZER PURCHASES (LBS/MO)          00001080
                                                                            00001081
                                                                            00001082
                  FUEL INPUTS                                               00001083
A   YFL1.K=DLINF3(GUFR.JK*EFM.K*KCG,1.5)                                    00001090
R   GUFR.KL=FUS.K+FPUR.K      GASOLINE USED                                 00001092
C   KCG=32000 KCAL/GAL       ENERGY VALUE OF GASOLINE                       00001093
A   EFM.K=TABXT(EFMT,GPA.K,0,25,5)   FUEL EFFECTIVENESS                     00001110
T   EFMT=5/3.63/2.63/1.5/1.25/1                                             00001111
A   GPA.K=GUFR.JK/(ARIN.JK+1E-2)       UNIT FUEL USE (GAL/ACRE)             00001113
A   FUS.K=FIFGE(0,MIN(FUNOR*FDM.K*ARI.K,GAF.K),GHA,TOTAR.K)  (GAL/MO)       00001130
A   GAF.K=FIFGE(GUP.K/CFG,0,CIAM,MCIAM) GAS AVAILABLE FOR FUEL (GAL EQUI 00001132
C   CFG=250 CUFT/GAL     BIOGAS-GASOLINE CONVERSION                         00001133
A   FPUR.K=FIFGE(0,FIFGE(MAX((FUNOR*ARI.K)-SMOOTH(GAF.K,2),0),0,CIAM,       00001150
X     MCIAM),GHA,TOTAR.K)                  FUEL PURCHASES (GAL/MO)          00001151
C   FUNOR=10 GAL/ACRE                                                       00001152
A   FDM.K=TABHL(FDMT,DR.K,-12,12,6)   FUEL USE MODIFIER FROM CASH AVAILAB00001160
T   FDMT=2/1.93/1.8/1.6/1                                                   00001161
C   CIAM=3000 $   INVESTMENT IN AGRICULTURAL MACHINERY                      00001162
C   MCIAM=3000 $  MIN INV IN AGRI MACH                                      00001163
                                                                            00001164
               CROP AREA                                                    00001165
L   ARDES.K=FIFGE((((FOODNOR+ACONS+(AVPM.J/DCAL))*12)+FOODRES+(DOLRES.J/ 00001170
X     DCAL))/YIDSM.J,ARDES.J-DT*ARIN.JK,0.25,MONTH.J-0.2)                   00001171
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                    TOTAL AREA PROJECTED FOR YEAR                    00001172
N  ARDES=ARD                                                         00001173
C  ARD=1                                                             00001174
A  YLDSM.K=SMOOTH(YLDR.JK,APER)                                      00001180
N  YLDSM=24000000                                                    00001181
L  ANIC.K=ANIC.J+DT*(AROUT.JK-ARIN.JK)  AREA NOT IN CULTIVATION (ACRES) 00001190
N  ANIC=TCA                                                          00001191
N  TCA=CIA/DPAC   TOTAL CULTIVABLE AREA (ACRES)                      00001192
C  DPAC=300 $/ACRE       UNIT LAND COST                              00001193
C  CIA=24000 $            INVESTMENT IN CROPLAND                     00001194
R  AROUT.KL=DELAY3(AROUT1.JK,1.5)  AREA REMOVED FROM CULTIVATION (AC/MO) 00001200
R  AROUT1.KL=DELAY3(ARIN.JK,1.5)                                     00001202
N  AROUT1=0                                                          00001203
R  ARIN.KL=ARI.K          AREA PUT INTO CULTIVATION (AC/MO)          00001220
A  ARI.K=MIN(MIN(ANIC.K,MAX(TOTAR.K-AREA.K,0)),ARDES.K)              00001222
A  AREA.K=TCA-ANIC.K        AREA IN CULTIVATION                      00001240
A  TOTAR.K=TABHL(TOTART,MONTH.K,0,12,1)  SEASONAL AREA LIMITATIONS   00001250
T  TOTART=.25/.25/.25/.25/32/80/80/32/16/.25/.25/.25/.25 ACRES       00001251
N  GHA=CIGA/DAGH        GREENHOUSE AREA (ACRES)                      00001252
C  DAGH=100000 $/ACRE     UNIT GREENHOUSE COST                       00001253
C  CIGA=25000 $             INVESTMENT IN GREENHOUSE                 00001254
                                                                     00001255
*               CASH-LABOR SECTOR                                    00001256
L  DOLAV.K=DOLAV.J+DT*(CLABR.JK+DSALES.JK-DOLPD.JK)  CASH AVAILABLE ($) 00001260
N  DOLAV=DOLA                                                        00001261
C  DOLA=14000                                                        00001262
R  DSALES.KL=SALESR.JK*DCAL             CASH FROM FOOD SALES ($/MO)  00001270
C  DCAL=0.00025 $/KCAL     UNIT CROP VALUE                           00001271
R  CLABR.KL=CLABI.K           CASH FROM WORK ($/MO)                  00001280
A  CLABI.K=MIN(CLABD.K,LAVC.K*WR)  EARNINGS ($/MO)                   00001282
C  WR=3.5 $/HR  WAGE RATE                                            00001283
A  CLABD.K=FIFGE(0,(DOLRES.K-DOLAV.K)/RT.K,DOLAV.K,DOLRES.K)         00001284
                            CASH DESIRED FROM LABOR ($/MO)           00001285
A  RT.K=TABHL(RTT,DR.K,0,12,3)  RECOVERY TIME, MONTHS                00001310
T  RTT=3/6/9/12/15 MONTHS                                            00001311
A  DR.K=DOLAV.K/(AVPM.K+1E-6)          EXPENSE RATIO                 00001313
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A   AVPM.K=SMOOTH(DOLPD.JK,APER)       SMOOTHED MONTHLY PAYMENTS                 00001330
C   APER=12 MONTHS  SMOOTHING PERIOD                                             00001331
A   DOLRES.K=AVPM.K*RESC      RESERVE CASH                                       00001340
C   RESC=0 MONTHS RESERVE PERIOD                                                 00001341
A   LAVC.K=LAVCM.K-LABCM.K        LABOR AVAILABLE FOR CASH (HRS/MO)              00001350
A   LABC.K=CLABI.K/WE           CASH LABOR (HRS/MO)                              00001360
S   TLAB.K=LABAV-LAVC.K+LABC.K      TOTAL LABOR (HRS/MO)                         00001370
N   LABAV=NOPERS*AHP     TOTAL LABOR AVAILABLE (HRS/MO)                          00001371
C   AHP=100 HRS/PERS-MO    AVERAGE UNIT LABOR AVAILABLITY                        00001372
                                                                                 00001373
                           EXPENSES                                              00001374
R   DOLPD.KL=AMORT+FXC+EXP.K              TOTAL EXPENDITURES   ($/MO)            00001380
N   DOLPD=8393                                                                   00001381
N   AMORT=TCI*MP     MORTGAGE PAYMENT ($/MO: 7.5%, 40 YRS)                       00001382
N   TCI=CISTO+CICOL+CIWG+CIBLDG+CIGA+CIA+CIAM+CIAP+MDCI+GSCI+CIELG+CIW           00001383
                                      TOTAL CAPITAL INVESTMENT                   00001384
C   MP=.00658 $/$-MO                                                             00001385
N   FXC=TCI*TXINRE         FIXED OPERATING COSTS ($/MO)                          00001386
C   TXINRE=.00583 $/$-MO                                                         00001387
                                                                                 00001388
                           VARIABLE COSTS                                        00001389
A   EXP.K=AGCOST.K+DANF.K+DPURF.K+DAUXRQ.K+DCOOK.K+DELRQ.K+DHWRQ.K+              00001390
X     DFERP.K+DFPUR.K      TOTAL ENERGY AND FOOD EXPENDITURES                    00001391
A   AGCOST.K=ARIN.JK*DACR          AGRICULTURAL EXPENSES                         00001392
C   DACR=25 $/ACRE                                                               00001393
A   DANF.K=PURAN.K*DKCALF       FEED EXPENDITURES ($/MO)                         00001394
C   DKCALF=.00007 $/KCAL                                                         00001395
A   DPURF.K=PURF.K*DFCAL                FOOD EXPENDITURES                        00001396
C   DFCAL=.0005 $/KCAL                                                           00001397
A   DAUXRQ.K=AUXRQ.K*DBTU           AUXILLARY HEAT                               00001398
A   DCOOK.K=CFPUR.K*DBTU            COOKING FUEL                                 00001399
A   DHWRQ.K=HWERQ.K*DBTU            HOT WATER                                    00001401
C   DBTU=.000005 $/BTU                                                           00001402
A   DELRQ.K=NELRQ.K*DKWH            NET ELECTRICITY                              00001403
C   DKWH=.05 $/KWH                                                               00001404
A   DFERP.K=FERPUR.JK*DPF        FERTILIZER EXPENSES                             00001405
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C   DPF=.0125 $/LB                                                                  00001406
A   DFPUR.K=FPUR.K*DCF                      FUEL EXPENSES                           00001407
C   DCF=.0026 $/CUFT                                                                00001408
                                                                                    00001482
              TIME SECTOR                                                           00001483
A   MONT.K=FIFGE(-47,1,MONTH.K,11.8)                                                00001490
L   MONTH.K=MONTH.J+DT*MONT.J                                                       00001492
N   MONTH=MO                                                                        00001493
C   MO=12                                                                           00001494
                                                                                    00001503
               CONTROL CARDS                                                        00001504
PLOT   AREA=*,ARIN=+/FOODAV=F,YLDR=Y,SALESR=S,PURF=P/DOLAV/TLAB,LABAG               00001505
PRINT  MONTH,AREA,ARIN,AROUT,FOODAV,YLDR,DOLAV,TLAB,LABAG,TCONS                     00001506
SPEC   DT=0.25/LENGTH=0/PRTPER=3/PLTPER=1                                           00001507
RUN                                                                                 00001508
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NAME      NO    T  DEFINITION
   WHERE USED

ACOL       8.3 N  COLLECTOR AREA (SQFT) <8.3>
   SCOLRI,A,8.2
ACOLT      8.4 T
   ACOL,N,8.3
ACONS     83.1 N
   ACONSI,A,83/PURAN,A,83.3/ARDES,L,117
ACONSI    83   A  ANIMAL CONS FROM AV FOOD <83>
   CONSR,R,80/PURAN,A,83.3/SALESR,R,86
ACW       47.2 N  WOODLOT SIZE (ACRES) <47.2>
   WGR,N,47.1
AGCOST   139.2 A  AGRICULTURAL EXPENSES <139.2>
   EXP,A,139
AHP      137.2 C  AVERAGE UNIT LABOR AVAILABLITY <137.2>
   LABAV,N,137.1
ALABN     94.5 C
   LABAG,A,94.2
ALAM      97.2 A
   LAM,A,97
ALAMT     97.3 T
   ALAM,A,97.2
AMORT    138.2 N  MORTGAGE PAYMENT ($/MO: 7.5%, 40 YRS)
                    <138.2>
   DOLPD,R,138
ANIC     119   L  AREA NOT IN CULTIVATION (ACRES) <119>
         119.1 N
   ARI,A,122.2/AREA,A,124
ANYLD     87   N  FOOD FROM ANIMALS (KCAL/MO) <87>
   FOODAV,L,79
APER     133.1 C  SMOOTHING PERIOD <133.1>
   YLDSM,A,118/AVPM,A,133
ARD      117.4 C
   ARDES,N,117.3
ARDES    117   L  TOTAL AREA PROJECTED FOR YEAR <117>
         117.3 N
   ALAM,A,97.2/ARI,A,122.2
AREA     124   A  AREA IN CULTIVATION <124>
   LABAG,A,94.2/ARI,A,122.2/PLOT,150.5/PRINT,150.6
ARI      122.2 A
   LABAG,A,94.2/ALAM,A,97.2/FERUD,A,103.3/FUS,A,113/FPUR,A,
     115/ARIN,R,122
ARIN     122   R  AREA PUT INTO CULTIVATION (AC/MO) <122>
   YFM1,A,100.2/GPA,A,111.3/ARDES,L,117/ANIC,L,119/AROUT1,R,
     120.2/AGCOST,A,139.2/PRINT,150.6
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AROUT    120   R  AREA REMOVED FROM CULTIVATION (AC/MO) <120>
   ANIC,L,119/PRINT,150.6
AROUT1   120.2 R
         120.3 N
   AROUT,R,120
AT        26.2 C  AVERAGE ALPHA-TAU PRODUCT <26.2>
   BSGAIN,A,26
AUXRQ     31   A  AUXILIARY HEAT REQD (BTU/MC) <31>
   DAUXRQ,A,139.8
AVPM     133   A  SMOOTHED MONTHLY PAYMENTS <133>
   ARDES,L,117/DR,A,131.3/DOLPES,A,134
AVW       20.2 A  MONTHLY WIND SPEED (MPH) <20.2>
   VW,A,20/VDEV,A,20.5
AWIN      26.1 C  AREA OF SOUTH WINDOWS <26.1>
   BSGAIN,A,26
AWP       72   R  ANIMAL WASTE PRODUCED, LBS <72>
   WAV,L,71
BAREA     27.4 C  SURFACE AREA ABOVE GROUND <27.4>
   BLOSS,A,27
BGAREA    27.5 C  SURFACE AREA BELOW GROUND <27.5>
   BLOSS,A,27
BHREQ     25   A  BUILDING HEAT REQD (BTU/MO) <25>
   SSH,A,11/SAD,A,12.4/AUXRQ,A,31
BLOSS     27   A  BUILDING HEAT LOSS,  BTU/MONTH <27>
   BHREQ,A,25
BSGAIN    26   A  BUILDING SOLAR GAIN (BTU/MO) <26>
   BHREQ,A,25
BTUC      39.4 C
   WOODE,A,39.2/WUR,R,44/CWN,N,47.6
BTUF      41.3 C
   GEAC,A,41.2/GUC,A,62.5
CA        47.5 C
   WGR,N,47.1
CEFF       9.1 C  AVERAGE COLLECTOR EFFICIENCY <9.1>
   SCOL,A,9
CELG      35.3 N  GENERATOR RATING (KWE) <35.3>
   MXGEN,N,35.1
CEP       38.2 C
   TCD,N,38.1
CFG      113.3 C  BIOGAS-GASOLINE CONVERSION <113.3>
   GUF,A,62.3/GAF,A,113.2
CFK       37.1 C  BIOGAS-ELECTRICITY CONVERSION (25%) <37.1>
   EAG,A,37/GEAC,A,41.2/GUE,A,62.4
CFPUR     38   A  COOKING FUEL PURCHASES (BTU/MO) <38>
   DCOOK,A,139.9
CIA      119.4 C  INVESTMENT IN CROPLAND <119.4>
   TCA,N,119.2/TCI,N,138.3
CIAM     116.2 C  INVESTMENT IN AGRICULTURAL MACHINERY
                    <116.2>
   HLC,N,78.3/GAF,A,113.2/FPUR,A,115/TCI,N,138.3
CIAP      87.4 C  INVESTMENT IN ANIMALS AND PASTURE <87.4>
   NOAN,N,87.2/TCI,N,138.3
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CIBLDG   26.3 C  INVESTMENT IN BUILDINGS <26.3>
   TCI,N,138.3
CICOL     8.5 C  CAPITAL INVESTED IN SOLAR COLLECTOR <8.5>
   ACOL,N,8.3/TCI,N,138.3
CIELG    35.5 C  INVESTMENT IN GAS ELECTRICAL GENERATOR
                   <35.5>
   CELG,N,35.3/HLD,N,76.1/TCI,N,138.3
CIGA    125.4 C  INVESTMENT IN GREENHOUSE <125.4>
   GHA,N,125.2/TCI,N,138.3
CISTO    17.5 C  CAPITAL INVESTED IN STORAGE <17.5>
   SCAP,N,17.9/TCI,N,138.3
CIW      47.3 C  CAPITAL INVESTED IN WOODLOT <47.3>
   ACW,N,47.2/TCI,N,138.3
CIWG     24.3 C  CAPITAL INVESTMENT IN WIND PLANT <24.3>
   NOMGEN,N,24.1/TCI,N,138.3
CLABD   128.4 A  CASH DESIRED FROM LABOR ($/MO) <128.4>
   CLABI,A,128.2
CLABI   128.2 A  EARNINGS ($/MO) <128.2>
   CLABR,R,128/LABC,A,136
CLABR   128   R  CASH FROM WORK ($/MO) <128>
   DOIAV,L,126
COLT      4.5 T  BTU/SQFT-DAY AT 44DEG N LAT <4.5>
   MXCOL,A,4.4
CONSI    80.2 A  HUMAN CONSUMPTION <80.2>
   CONSR,R,80/ACONSI,A,83/SALESR,R,86/TCONS,S,86.5
CONSM    82   A  CONSUMPTION MULTIPLIER <82>
   CONSI,A,80.2
CONSMT   82.1 T
   CONSM,A,82
CONSNOR  80.5 C  UNIT FOOD CONSUMPTION <80.5>
   FOODNOR,N,80.3
CONSR    80   R  FOOD CONSUMPTION (KCAL/MO) <80>
   FOODAV,L,79
CP       18.4 C
   SHCAP,N,17.7/SMIN,N,17.8/TT,A,19/HWC,N,32.2
CPM      55.1 C  COMPOSTING PERIOD <55.1>
   CR,R,55
CR       55   R  FERTILIZER PRODUCED FROM COMPOST, LBS/MO
                   <55>
   FERAV,L,50
CWN      47.6 N  WOOD NEEDED FOR COOKING (CORDS/MO) <47.6>
   MWCP,A,47
CWP      68   R  CROP WASTE PRODUCTION, LBS/MO <68>
   WAV,L,71
DACR    139.3 C
   AGCOST,A,139.2
DAGH    125.3 C  UNIT GREENHOUSE COST <125.3>
   GHA,N,125.2
DANF    139.4 A  FEED EXPENDITURES ($/MO) <139.4>
   EXP,A,139
DAUXRQ  139.8 A  AUXILLARY HEAT <139.8>
   EXP,A,139
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DAW       47.4 C
   ACW,N,47.2
DBTU     140.2 C
   DAUXRQ,A,139.8/DCOOK,A,139.9/DHWRQ,A,140.1
DCAL     127.1 C  UNIT CROP VALUE <127.1>
   ARDES,L,117/DSALES,R,127
DCF      140.8 C
   DFPUR,A,140.7
DCOOK    139.9 A  COOKING FUEL <139.9>
   EXP,A,139
DELRQ    140.3 A  NET ELECTRICITY <140.3>
   EXP,A,139
DFCAL    139.7 C
   DPURF,A,139.6
DFERP    140.5 A  FERTILIZER EXPENSES <140.5>
   EXP,A,139
DFPUR    140.7 A  FUEL EXPENSES <140.7>
   EXP,A,139
DFR       53.2 A  WASTE  DIGESTED (LBS/MO) <53.2>
   DFRF,R,53/DFRG,R,60/WDR,R,69/WCRI,A,75.2/LABMD,A,76
DFRF      53   R  DIGESTER LOADING IN TERMS OF FERTILIZER,
                    LBS/MO <53>
   FPR,R,52
DFRG      60   R  DIGESTER LOADING IN TERMS OF GAS, CU FT/MO
                    <60>
   GPRI,A,58.2
DHWRQ    140.1 A  HOT WATER <140.1>
   EXP,A,139
DKCALF   139.5 C
   DANF,A,139.4
DKWH     140.4 C
   DELRQ,A,140.3
DOLA     126.2 C
   DOLAV,N,126.1
DOLAV    126   L  CASH AVAILABIE ($) <126>
         126.1 N
   CLABD,A,128.4/DR,A,131.3/PLOT,150.5/PRINT,150.6
DOLPD    138   R  TOTAL EXPENDITURES  ($/MO) <138>
         138.1 N
   DOLAV,L,126/AVPM,A,133
DOLRES   134   A  RESERVE CASH <134>
   ARDES,L,117/CLABD,A,128.4
DPA       87.3 C
   NOAN,N,87.2
DPAC     119.3 C  UNIT LAND COST <119.3>
   TCA,N,119.2
DPF      140.6 C
   DFERP,A,140.5
DPM       52.1 C  DETENTION PERIOD <52.1>
   FPR,R,52/GPRI,A,58.2
DPURF    139.6 A  FOOD EXPENDITURES <139.6>
   EXP,A,139
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DR       131.3 A  EXPENSE RATIO <131.3>
   FDM,A,116/RT,A,131
DSALES   127   R  CASH FROM FOOD SALES ($/MO) <127>
   DOLAV,L,126
DTEM      18.2 C  RANGE OF USEFUL TEMPERATURES <18.2>
   SHCAP,N,17.7
DTHT      18.3 C  RANGE OF THRESHOLD TEMPERATURE <18.3>
   SHCAP,N,17.7/SMIN,N,17.8
EAG       37   A  MAX ELECT POSS FROM GAS <37>
   GENR,A,35/GEAC,A,41.2
ECWC      68.2 C  EFFICIENCY OF CROP WASTE COLLECTION <68.2>
   CWP,R,68
EFM      111   A  FUEL EFFECTIVENESS <111>
   YFL1,A,109
EFMT     111.1 T
   EFM,A,111
EFWC      73   A  EFFICIENCY OF ANIMAL WASTE COLLECTION <73>
   AWP,R,72
EFWCT     73.2 T
   EFWC,A,73
ELRQ      34.1 N  ELECTRICITY REQD (KWH/MO) <34.1>
   NELRQ,A,34/GELD,A,36
ELUS      34.2 C
   ELRQ,N,34.1
EXP      139   A  TOTAL ENERGY AND FOOD EXPENDITURES <139>
   STCM,N,17.2/DOLPC,R,138
FA        79.3 C
   FOODAV,N,79.2
FDM      116   A  FUEL USE MODIFIER FROM CASH AVAILAB <116>
   FUS,A,113
FDMT     116.1 T
   FDM,A,116
FER       50.3 C
   FERAV,N,50.2
FERA     105.2 A  MODIFIER FROM AREA LIMITATIONS <105.2>
   FERMOD,A,105
FERAV     50   L  TOTAL FERTILIZER USE (LBS/MO) <50>
          50.2 N
   FERHF,A,51/FERUR,R,102
FERF     105.3 A  MODIFIER FROM PREVIOUS APPLICATIONS <105.3>
   FERMOD,A,105
FERFT    105.5 T
   FERF,A,105.3
FERHF     51   A  FERTILIZER USED ON HAYFIELDS <51>
   FERAV,L,50/FERUR,R,102
FERHFD    51.1 N  FERT DESIRED FOR HAYFIELDS <51.1>
   FERHF,A,51
FERMOD   105   A  FERTILIZER USE MODIFIER <105>
   FERUD,A,103.3
FERNOR   103.4 C
   FERUD,A,103.3
FERPUR   108   R  FERTILIZER PURCHASES (LBS/MO) <108>
   FERAV,L,50/DFERP,A,140.5
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FERUD    103.3 A  FERTILIZER USE DESIRED (LBS/MO) <103.3>
   FERUR,R,102/FERURD,R,103
FERUR    102   R  FERTILIZER USE FOR CROPS <102>
         102.1 N
   FERAV,L,50/YFM1,A,100.2/FERF,A,105.3/FERPUR,R,108
FERURD   103   R
         103.1 N
   FERF,A,105.3/FERPUR,R,108
FOODAV    79   L  FOOD AVAILABLE (KCAL) <79>
          79.2 N
   CONSI,A,80.2/CONSM,A,82/ACONSI,A,83/PURF,A,84/SALESR,R,86
     PRINT,150.6
FOODNOR   80.3 N  NORMAL FOOD CONSUMPTION (KCAL/MO) <80.3>
   CONSI,A,80.2/CONSM,A,82/PURF,A,84/FOODRES,N,86.1/ARDES,L,
     117
FOODRES   86.1 N  FOOD RESERVE (KCAL) <86.1>
   SALESR,R,86/ARDES,L,117
FPAF      51.2 C
   FERHFD,N,51.1
FPR       52   R  FERTILIZER PRODUCED IN DIGESTER, LBS/MO
                    <52>
   FERAV,L,50
FPUR     115   A  FUEL PURCHASES (GAL/MO) <115>
   GUFR,R,109.2/DFPUR,A,140.7
FUNOR    115.2 C
   FUS,A,113/FPUR,A,115
FUS      113   A  (GAL/MO) <113>
   GUF,A,62.3/GUFR,R,109.2
FWC       70   A  FRACTION COMPOSTED <70>
   WCRI,A,75.2
FWCT      70.1 T
   FWC,A,70
FXC      138.6 N  FIXED OPERATING COSTS ($/MO) <138.6>
   DOLPD,R,138
FYAW      68.1 C  OF YIELD AS WASTE <68.1>
   CWP,R,68
GAF      113.2 A  GAS AVAILABLE FOR FUEL (GAL EQUI <113.2>
   FUS,A,113/FPUR,A,115
GALCF     18.5 C
   STCM,N,17.2
GAS       56.2 C
   GASAV,N,56.1
GASAV     56   L  GAS AVAILABLE, CUFT <56>
          56.1 N
   GWR,R,61/GUP,A,67
GCF       61.5 C  GAS COMPRESSION FACTOR(1500 PSI) <61.5>
   GWR,R,61
GEAC      41.2 A  GAS ENERGY AVAILABLE (BTU/MO) <41.2>
   GEUS,A,41
GELD      36   A  ELECTRICITY DESIRED FROM GAS (KWH/MO) <36>
   GENR,A,35
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GENR      35    A   ELECT FROM BIOGAS (KWH/MO) <35>
   NELRQ,A,34/GUE,A,62.4
GEUS      41    A   ENERGY FROM GAS (BTU/MO) <41>
   CFPUR,A,38/GUC,A,62.5
GHA      125.2  N   GREENHOUSE AREA (ACRES) <125.2>
   LAM,A,97/FERA,A,105.2/FUS,A,113/FPUR,A,115
GHRS      35.2  C   HOURS OF GEN OPERATION <35.2>
   MXGEN,N,35.1
GPA      111.3  A   UNIT FUEL USE (GAL/ACRE) <111.3>
   LFM,A,99/EFM,A,111
GPP       32.3  C
   HWC,N,32.2
GPR       58    R   GAS PRODUCTION, CUFT/MO <58>
   GASAV,L,56
GPRI      58.2  A   GAS PRODUCTION INDICATED <58.2>
   PHR,R,57/GPR,R,58/GWR,R,61/GUP,A,67
GSCI      61.4  C   INVESTMENT IN STORAGE TANK <61.4>
   GSTC,N,61.2/TCI,N,138.3
GST       61.3  T
   GSTC,N,61.2
GSTC      61.2  N   STORAGE TANK  SIZE <61.2>
   GWR,R,61
GUC       62.5  A   GAS USED FOR COOKING (CUFT/MO) <62.5>
   GURI,A,62.2
GUE       62.4  A   GAS USED FOR ELECTRICITY (CUFT/MO) <62.4>
   GEAC,A,41.2/GURI,A,62.2
GUF       62.3  A   GAS USED FOR FUEL (CUFT/MO) <62.3>
   EAG,A,37/GURI,A,62.2
GUFR     109.2  R   GASOLINE USED <109.2>
   YFL1,A,109/GPA,A,111.3
GUP       67    A   GAS USE POSSIBLE (CUFT/MO) <67>
   EAG,A,37/GAF,A,113.2
GUR       62    R   GAS USE (CUFT/MO) <62>
   GASAV,L,56
GURI      62.2  A
   GWR,R,61/GUR,R,62
GWR       61    R   GAS WASTED (CUFT/MO) <61>
   GASAV,L,56
GYLD      60.1  C   GAS YIELD PER LB DRY SOLIDS <60.1>
   DFRG,R,60
HLC       78.3  N   UNIT RATE OF COMPOST LABOR (HRS/LB) <78.3>
   LABCM,A,78
HLD       76.1  N   UNIT RATE OF DIGESTER LABOR (HRS/LB) <76.1>
   LABMD,A,76
HPA       87.6  C
   LABAN,N,87.5
HPC       48.3  C
   WCUTR,R,45.2/LABW,A,48
HWC       32.2  N   HW THERMAL CAPY PER DEG(F) HEATING REQD
                      <32.2>
   SHW,A,32/HWERQ,A,33
HWERQ     33    A   HW AUXILIARY HEAT REQD (BTU/MO) <33>
   DHWRQ,A,140.1
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INFIL     27.7 C  INFILTRATION FACTOR <27.7>
   BLOSS,A,27
IWT       32.1 C  INLET WATER TEMP <32.1>
   SHW,A,32
KCALH     93.1 C  USEFUL ENERGY OF LABOR <93.1>
   YLB1,A,93
KCG      109.3 C  ENERGY VALUE OF GASOLINE <109.3>
   YFL1,A,109
KWHPK     23   A  UNIT  MONTHLY OUTPUT (KWH/MO-KWE) <23>
   WGENR,A,24
KWHT      23.1 T
   KWHPK,A,23
LABAG     94.2 A
   LAVW,A,48.2/LABR,R,94/PLOT,150.5/PRINT,150.6
LABAN     87.5 N  LABOR REQUIRED FOR ANIMAL CARE  (HRS/MO)
                    <87.5>
   LAVAG,A,94.3
LABAV    137.1 N  TOTAL LABOR AVAILABLE (HRS/MO) <137.1>
   LAVAG,A,94.3/TLAB,S,137
LABC     136   A  CASH LABOR (HRS/MO) <136>
   TLAB,S,137
LABCM     78   A  COMPOSTING LABOR (HRS/MO) <78>
   LAVC,A,135
LABMD     76   A  DIGESTER LABOR <76>
   LAVAG,A,94.3
LABNOR    94.4 C
   LABAG,A,94.2
LABR      94   R  AGRICULTURAL LABOR (HRS/MO) <94>
   YLB1,A,93
LABW      48   A  WOODCUTTING LABOR (HRS/MO) <48>
   WCUTR,R,45.2/LAVCM,A,78.2
LAM       97   A  LABOR MULTIPLIER FROM AREA <97>
   LABAG,A,94.2
LAVAG     94.3 A  LABOR AVAILABLE FOR AGRICULTURE (HRS/MO)
                    <94.3>
   LAVW,A,48.2/LABAG,A,94.2
LAVC     135   A  LABOR AVAILABLE FOR CASH (HRS/MO) <135>
   CLABI,A,128.2/TLAB,S,137
LAVCM     78.2 A  LABOR AVAIL FOR COMPOSTING (HRS/MO) <78.2>
   LABCM,A,78/LAVC,A,135
LAVW      48.2 A  LABOR AVAILABLE FOR WOODCUTTING (HRS/MO)
                    <48.2>
   LABW,A,48/LAVCM,A,78.2
LENGTH
   SPEC,150.7
LFM       99   A  LABOR MULTIPLIER FROM FUEL USE <99>
   LABAG,A,94.2
LFMT      99.1 T
   LFM,A,99
MCIAM    116.3 C  MIN INV IN AGRI MACH <116.3>
   GAF,A,113.2/FPUR,A,115
MDCAP     53.6 N  DIGESTER CAPACITY <53.6>
   MXCP,N,53.4
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MDCAPT    53.7 T
   MDCAP,N,53.6
MDCI      53.8 C  CAPITAL INVESTED IN BIOGAS PLANT <53.8>
   MDCAP,N,53.6/TCI,N,138.3
MO       149.4 C
   MONTH,N,149.3
MONT     149   A
   MONTH,L,149.2
MONTH    149.2 L
         149.3 N
   NORSUN,A,1.2/MXSRAD,A,4/MXCOL,A,4.4/AVW,A,20.2/TOU,A,28.1
     TG,A,30/EFWC,A,73/ALAM,A,97.2/ARDES,L,117/TOTAR,A,125
     MONT,A,149/PRINT,150.6
MP       138.5 C
   AMORT,N,138.2
MWCP      47   A  MAX WOOD CUTTING POSS (CORDS/MO) <47>
   LABW,A,48
MXCOL      4.4 A  MAX DAILY SUN ON 60DEG COL <4.4>
   SCOL,A,9
MXCP      53.4 N  MAXIMUM DIGESTER LOADING, LBS/MO <53.4>
   DFR,A,53.2/FWC,A,70
MXGEN     35.1 N  MAX GEN POSS  (KWH/MO) <35.1>
   GENR,A,35
MXSRAD     4   A  MAX CLEAR DAY SUN ON S WALL <4>
   SGAIN,A,6
NELRQ     34   A  NET ELEC PURCHASES (SALES) (KWH/MO) <34>
   DELRQ,A,140.3
NIC        8.6 C  NUMBER OF IDENTICAL COLLECTORS <8.6>
   ACOL,N,8.3
NID       53.9 C  NUMBER OF IDENTICAL DIGESTERS <53.9>
   MXCP,N,53.4/MDCAP,N,53.6
NIS       17.6 C  NUMBER OF IDENTICAL STORAGE TANKS <17.6>
   SHCAP,N,17.7/SMIN,N,17.8/SCAP,N,17.9/TT,A,19
NIT       61.6 C  NUMBER OF IDENTICAL TANKS <61.6>
   GSTC,N,61.2
NIW       24.4 C  NUMBER OF IDENTICAL WIND GENERATORS <24.4>
   WGENR,A,24/NOMGEN,N,24.1
NOAN      87.2 N  NUMBER OF ANIMALS <87.2>
   FERHFD,N,51.1/AWP,R,72/ACONS,N,83.1/ANYLD,N,87/LABAN,N,
     87.5
NOMGEN    24.1 N  GENERATOR RATING <24.1>
   WGENR,A,24
NOMT      24.2 T
   NOMGEN,N,24.1
NOPERS    80.4 C
   HWC,N,32.2/ELRQ,N,34.1/TCD,N,38.1/AWP,R,72/FOODNOR,N,80.3
     LABAV,N,137.1
NORSUN     1.2 A  MEAN % OF POSS SUN <1.2>
   PERSUN,A,1/SNDV,A,1.5
NSAV      12   A  NET SOLAR AVAILABLE FOR SPACE HEATING (BTU/
                     MO) <12>
   SSH,A,11/TT,A,19/SHW,A,32
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PERSUN     1   A  CURRENT % OF POSS SUN <1>
   SGAIN,A,6/SCOL,A,9
PHP       57.1 C  PERCENT OF OUTPUT FOR HEAT <57.1>
   PHR,R,57/GWR,R,61/GUP,A,67
PHR       57   R  PROCESS HEAT (CUFT/MO) <57>
   GASAV,L,56
PLTPER
   SPEC,150.7
PRTPER
   SPEC,150.7
PURAN     83.3 A  FEED PURCHASED (KCAL/MO) <83.3>
   DANF,A,139.4
PURF      84   A  FOOD PURCHASED (KCAL/MO) <84>
   TCONS,S,86.5/DPURF,A,139.6/PLOT,150.5
RES       86.2 C
   FOODRES,N,86.1
RESC     134.1 C  RESERVE PERIOD <134.1>
   DOLRES,A,134
RT       131   A  RECOVERY TIME, MONTHS <131>
   CLABD,A,128.4
RTT      131.1 T
   RT,A,131
SAD       12.4 A  SOLAR AVAILABLE DIRECTLY <12.4>
   SAVC,A,12.3/STS,A,12.5
SALESR    86   R  FOOD SALES <86>
   FOODAV,L,79/DSALES,R,127/PLOT,150.5
SAVC      12.3 A  SOLAR AVAILABLE FROM COLLECTION <12.3>
   NSAV,A,12
SCAP      17.9 N  STORAGE VOLUME <17.9>
   STCM,N,17.2/SHCAP,N,17.7/SMIN,N,17.8/TT,A,19
SCAPT     18.1 T
   SCAP,N,17.9
SCOL       9   A  BTU/SQ FT-DAY <9>
   SCOLRI,A,8.2
SCOLR      8   R
   SOLAV,L,7
SCOLRI     8.2 A  SOLAR ENERGY COLLECTION (BTU/MO) <8.2>
   SCOLR,R,8/SAD,A,12.4/STS,A,12.5/SLOSSR,R,17
SGAIN      6   A  DAILY INCIDENCE ON S WALL (BTU/SQFT) <6>
   BSGAIN,A,26
SHCAP     17.7 N  HEAT CAPACITY OF STORAGE,  BTU <17.7>
   STS,A,12.5/SLOSSR,R,17
SHW       32   A  HW FROM STORAGE <32>
   SUSER,R,10/SLOSSR,R,17
SLOSSR    17   R  SOLAR ENERGY LOSSES <17>
   SOLAV,L,7
SMIN      17.8 N  THRESHOLD VALUE OF USEFUL SOLAR ENERGY
                     <17.8>
   NSAV,A,12
SNDV       1.5 A
   PERSUN,A,1
SOLA       7.3 C  SOLAR COLLECTION <7.3>
   SOLAV,N,7.2
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SOLAV      7   L  ENERGY IN SOLAR STORAGE,  BTU <7>
           7.2 N
   NSAV,A,12/STS,A,12.5/SLOSSR,R,17
SRADT      4.1 T  BTU/SQ FT/DAY AT 44 DEG N <4.1>
   MXSRAD,A,4
SSH        11   A  SOLAR SPACE HEATING (BTU/MO) <11>
   SUSER,R,10/SLOSSR,R,17/TT,A,19/AUXRQ,A,31/SHW,A,32
STCM       17.2 N  STORAGE THERMAL TIME CONSTANT <17.2>
   NSAV,A,12/SLOSSR,R,17
STS        12.5 A  SOLAR TEMP STORED <12.5>
   SAVC,A,12.3
SUNT       1.3 T  AT 44 DEG N  71 DEG W <1.3>
   NORSUN,A,1.2
SUSER      10   R  SOLAR ENERGY USE ,  BTU/MONTH <10>
   SOLAV,L,7
TCA       119.2 N  TOTAL CULTIVABLE AREA (ACRES) <119.2>
   ANIC,N,119.1/AREA,A,124
TCD        38.1 N  TOTAL COOKING ENERGY DEMAND (BTU/MO) <38.1>
   CFPUR,A,38/WUSE,A,39/GEUS,A,41/CWN,N,47.6
TCI       138.3 N  TOTAL CAPITAL INVESTMENT <138.3>
   AMORT,N,138.2/FXC,N,138.6
TCONS      86.5 S  TOTAL HUMAN CONSUMPTION (KCAL/MO) <86.5>
   PRINT,150.6
TDEV       28.4 C
   TO,A,28
TG         30   A  GROUND TEMPERATURE <30>
   BLOSS,A,27
TGT        30.1 T
   TG,A,30
TIN        27.6 C  INSIDE AIR TEMPERATURE <27.6>
   BHREQ,A,25/BLOSS,A,27
TLAB      137   S  TOTAL LABOR (HRS/MO) <137>
   PLOT,150.5/PRINT,150.6
TO         28   A  AVERAGE OUTSIDE TEMPERATURE <28>
   BHREQ,A,25/BLOSS,A,27
TOTAR     125   A  SEASONAL AREA LIMITATIONS <125>
   LAM,A,97/FERA,A,105.2/FUS,A,113/FPUR,A,115/ARI,A,122.2
TOTART    125.1 T
   TOTAR,A,125
TOU        28.1 A  MONTHLY MEAN OUTSIDE TEMPERATURE <28.1>
   TO,A,28
TOUT       28.2 T
   TOU,A,28.1
TT         19   A  TANK TEMP AFTER SPACE HEAT <19>
   SHW,A,32/HWERQ,A,33
TUVAL      27.2 C  NET U-VALUE FOR BUILDING, INCL WINDOWS
                     <27.2>
   BLOSS,A,27
TUVBG      27.3 C  NET U-VALUE FOR BELOW GROUND PORTION OF
                     BLDG <27.3>
   BLOSS,A,27
TXINRE    138.7 C
   FXC,N,138.6
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UAC       83.2 C
   ACONS,N,83.1
UAY       87.1 C
   ANYLD,N,87
UFR       53.5 C  UNIT LOADING RATE <53.5>
   MXCP,N,53.4
UGC       35.4 C
   CELG,N,35.3
UT        17.4 C  TANK THERMAL CONDUCTIVITY <17.4>
   STCM,N,17.2
VDEV      20.5 A  DEVIATION OF WIND FROM NORMAL <20.5>
   VW,A,20
VW        20   A  CURRENT AVERAGE WIND SPEED (MPH) <20>
   KWHPK,A,23
VWT       20.3 T  (AVERAGE OF PORTLAND AND EASTPORT) <20.3>
   AVW,A,20.2
WA        71.2 C
   WAV,N,71.1
WAV       71   L  DRY WASTE AVAILABLE LBS <71>
          71.1 N
   DFR,A,53.2/FWC,A,70/WCRI,A,75.2
WCR       75   R
   CR,R,55/WAV,L,71
WCRI      75.2 A  DRY WASTE COMPOSTED <75.2>
   WCR,R,75/LABCM,A,78
WCTR      45   R  RATE OF WOOD AVAILABILITY (CORDS/MO) <45>
   WOODAV,L,43
WCUTR     45.2 R
   WCTR,R,45
WD        45.3 C  WOOD DELAY TIME <45.3>
   WCTR,R,45
WDR       69   R  WASTE USE IN DIGESTER <69>
   WAV,L,71
WGENR     24   A  ELECTRICITY GENERATED, KWH/MO <24>
   NELRQ,A,34/GELD,A,36
WGR       47.1 N  WOOD GROWTH (CORDS/MO) <47.1>
   MWCP,A,47
WOOD      43.2 C
   WOODAV,N,43.1
WOODAV    43   L  WOOD AVAILABLE (CORDS) <43>
          43.1 N
   WOODE,A,39.2
WOODE     39.2 A  WOOD ENERGY AVAILABLE (BTU/MO) <39.2>
   WUSE,A,39
WPA       72.2 C  LBS/MO     WASTE PER ANIMAL UNIT <72.2>
   AWP,R,72
WPP       72.1 C  LBS/MO TOTAL SOLIDS, <72.1>
   AWP,R,72
WR       128.3 C  WAGE RATE <128.3>
   CLABI,A,128.2/LABC,A,136
WSF       39.3 C  WOOD STOVE EFFICIENCY <39.3>
   WOODE,A,39.2/WUR,R,44/CWN,N,47.6
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WUR        44    R  WOOD USE RATE (CORDS/MO) <44>
   WOODAV,L,43
WUSE       39    A  ENERGY FROM WOOD (BTU/MO) <39>
   CFPUR,A,38/GEUS,A,41/WUR,R,44
YFL        89.6 A  YIELD FROM FUEL <89.6>
   YLDR,R,89
YFL1       109   A
   YFL,A,89.6
YFM        89.7 A  YIELD MULT FROM FERTILIZER <89.7>
   YLDR,R,89
YFMT       89.8 T
   YFM,A,89.7
YFM1      100.2 A
   YFM2,A,100
YFM2      100   A
   YFM,A,89.7
YLB        89.5 A  CROF YIELD FROM LABOR <89.5>
   YLDR,R,89
YLB1       93    A
   YLB,A,89.5
YLDR       89    R  CROP YIELD (KCAL/MO) <89>
           89.1 N
   CWP,R,68/FOODAV,L,79/YLDSM,A,118/PLOT,150.5/PRINT,150.6
YLDSM     118   A
          118.1 N
   ARDES,L,117
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note - some errors
exist in eqns.
CH

write for errata sheet

- STAR RT
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