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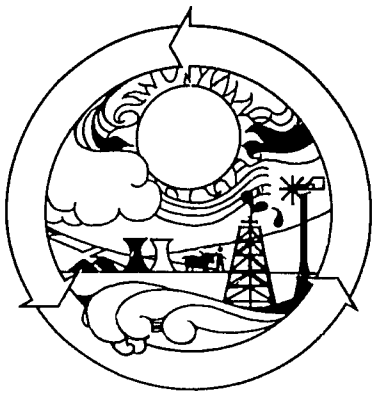

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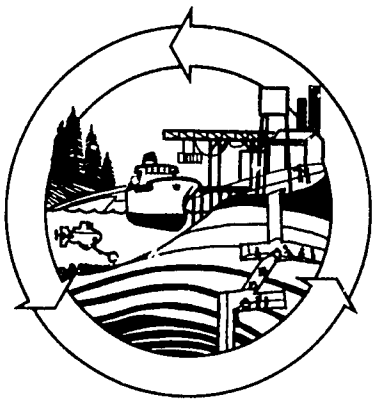

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CRITERIA FOR EVALUATING SMALL-SCALE RURAL ENERGY TECHNOLOGIES: THE FLERT APPROACH (FUEL-LINKED ENERGY RESOURCES AND TASKS)

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PREFACE

The energy future of the rural areas of poor countries is uncertain principally because it is becoming clear that increases in material welfare cannot be encouraged by increases in the use of petroleum fuels to the extent that characterized past development in other parts of the world. Because petroleum will never again have the political or economic availability it had in the past, a range of other sources will have to be developed, together with appropriate means to apply them for human benefit. Among the most promising of these sources are those that tap local flows of energy such as wind, sunlight, and flowing water or local traditional fuels such as dung, fuelwood, and agricultural residues. It is challenging to design and implement technologies that convert these sources into fuels that are more convenient, versatile, controllable, and efficient in use--characteristics that have drawn people to fossil fuels in the past.

The intent of this study is to develop a framework within which energy technologies for application in rural areas of developing Asia may be evaluated and compared. We encourage readers to respond to and criticize the suggested framework. Although the final framework may evolve from what is presented here, we intend that it remain highly structured. Such structure is important, not because it exactly represents reality, for it never can, but because, properly used, it provides for accountability--in a scientific sense so that studies can be repeated and hypotheses tested; in a political sense so that policy implementation can be verified and allocation of public resources determined; and in a moral sense so that surveys in the name of energy do not unreasonably and unconscionably interfere with village life and so that planned technological interventions are justifiable.

A preliminary description of the FLERT approach was presented at the Energy for Rural Development Conference in Chiangmai, Thailand, in early 1980 (Smith et al. 1980). Comments made by attendees at that conference and by other colleagues in Asia, Hawaii, and North America have been incorporated into this expanded version. A frequent suggestion was that a concrete example of the application of the FLERT approach would provide a useful companion to the general and conceptual descriptions found in the preliminary report. Consequently, in addition to providing more detail in this version, we have written a preliminary report of the application of the FLERT approach to a particular set of small-scale energy technologies. This report is entitled "Application of the FLERT Approach to Rural Household and Community Anaerobic Digestion Systems" (Santerre and Smith 1980). We hope that the two together will not only give the reader an understanding of the potential of the approach, but also supply useful insights into small-scale energy technologies for rural application.

INTRODUCTION

15. The concept of appropriate technology [is] viewed as being the technology mix contributing most to economic, social and environmental objectives, in relation to resource endowments and conditions of application in each country. Appropriate technology [is] also stressed as being a dynamic and flexible concept, which must be responsive to varying conditions and changing situations in different countries. UNIDO 1978a)

16. It [is] considered that, with widely divergent conditions in developing countries, no single pattern of technology or technologies could be considered as being appropriate, and that a broad spectrum of technologies should be examined and applied. An important overall objective of appropriate technological choice would be the achievement of greater technological selfreliance and increased domestic technological capability, together with fulfilment of other development goals. It [is] noted that, in most developing countries, a major development objective [is] to provide adequate employment opportunities and fulfilment of basic socio-economic needs of the poorer communities, mostly resident in rural areas . . . .(UNIDO 1978a)

289. . . . the appropriateness of any technology can be determined meaningfully only in terms of the specific technology and/or device, and the circumstances of its use. These circumstances [are] understood to include economic, material, and human resources, institutional capabilities, and availability and costs of alternatives. (UNIDO 1978b)

296. In general, energy options should satisfy techno-economic criteria. However, the Group emphasized that many of the aspects of providing new sources of energy to rural areas (such as improved sanitation, communication, education, lighting, safe drinking water, reduction of human drudgery) are difficult to quantify. Thus, economic cost-benefit analyses should be carried out with a long-range perspective and must include social and environmental considerations. (UNIDO 1978b)

297. Priority should be given to those energy technologies which exploit locally-available energy, human and material resources in the rural areas as far as possible, so that the rural income remains within the rural areas. Those schemes where the tradition of using these resources exists should be preferred, e.g., dung in the case of biogas,

wood in the case of charcoal production from wood plantations, etc. (UNIDO 1978b)

298. Rural energy supply schemes should be initiated after assessing the potential and necessary techno-economic parameters for various technologies, so that the supply matches the existing and projected energy demands. The land, resources, and subsidy requirements should be assessed. (UNITDO 1978b)

301. The institutional capability of developing countries, including training of personnel and expanding national institutions, should receive priority attention. A country's indigenous capability is essential in order to analyse and implement energy systems for the rural areas on any significant scale. (UNIDO 1978b)

The fuel crises caused by changes in the global price and availability of petroleum are widely interpreted to be the forerunner of a long-term and pervasive energy crisis for humanity. In the rural areas of Asia where sources of commercial energy are not readily available, oil-price rises have had little direct impact (Reddy and Prasad 1977). In a less spectacular way, however, the plight of the people in these areas has been exacerbated by the worldwide energy crisis. The changing status of petroleum has been translated into a significantly different view of the best path for rural development from what seemed desirable only a decade ago. For many rural areas, it no longer seems possible to plan for a future in which liquid fuels from petroleum play the major role. Consequently, greater emphasis is being placed on the production and use of traditional fuels, often in conjunction with technologies that modify traditional fuels to make them more convenient, controllable, clean, efficient, and storable--characteristics that, along with low prices, have drawn users to petroleum in the past.

It is recognized that successful introduction of these technologies depends on designing them carefully for the conditions under which they must operate--conditions sometimes significantly different from either those existing at present in rural areas or those characteristic of development successes in the past. Likewise, it is recognized that, even at the present comparatively high and increasing costs of petroleum, the economic competitiveness of many of these technologies is marginal as indicated by standard economic indicators.

Limitations of Economics

The quotations above succinctly state a point of view about the proper design of such technologies that is held by a growing number of people in many developing countries. From this point of view, technology's unarguable and considerable influences on social and environmental systems are identified as decision criteria in addition to technical and economic factors. As stated in

paragraph 296 above, this view holds that economic criteria are to be retained but understood to be insufficient in themselves to determine the appropriateness of technological applications. Indeed, the most important aggregate measure of a technology remains its economic appropriateness, but there are several reasons why economic analyses that must rely on price information fall short of providing enough information to confidently compare technologies. Some of these reasons are well recognized and general enough to be called "classic" (Mishan 1975).

1. Prices may be distorted because the markets they come from are imperfect. Government regulation, consumer ignorance, and industry monopoly all operate to increase the distortion.

2. Prices may be unobtainable for a number of the most interesting technologies or parts of technologies simply because not enough trade has occurred to establish markets.

3. Prices fail to incorporate a wide range of externalities involving environmental damage, social equity, human health, and other goods and services that are not directly bought and sold in the economic marketplace.

4. Economic accounts contain a particular view of time, expressed through present-value calculations, that may not be appropriate for decisions at every level of investment or for some types of costs and benefits (Smith 1980).

There is a further and important reason that economic analysis is inadequate when small-scale technologies are being evaluated, a reason peculiar to their scale (Brown and Smith 1980). In the United States, about 35 percent of total energy use is directly controlled by the final consumer, mostly in the form of automobile gasoline and domestic gas and electricity. The rest is used in intermediate production sectors along with the other inputs to production (Scharr et. 1979). In developing countries, commercial energy is similarly distributed. Noncommercial energy from traditional fuels, however, (almost by definition) is nearly all under the control of individuals or households in that the consumers are also the producers of those fuels. Thus, in those many countries where traditional fuels account for a large fraction of total energy use, control over energy uses may lie mostly in the hands of individuals. Furthermore, if energy use by individuals rather than by economic sectors is considered, it seems that most of the people in Asia and probably most of the world's people control the bulk of their own energy use. Most of the energy, however, is used in intermediate production sectors outside the direct control of individuals. This is the energy translation of the frequent observation that the large rural populations of developing countries tend to be isolated from the modern sectors of their own countries as well as from the developed countries and have low per capita monetary incomes (and energy use).

In intermediate sectors, decisions about energy use can be expected to be made on an economic basis. Energy costs will be balanced with the costs of other factors of production as far as the availability of fuels and knowledge

of the costs allow. It can be expected that economic efficiency measures such as return on investment can be applied with some success as a decision and planning tool. In the final consuming sector, on the other hand, while an economic calculus will be pertinent, a wide range of other factors will often dominate. Social, religious, and political concerns will influence decisions to a significant extent; and in some circumstances the simple dictates of survival may overwhelm all other considerations.

This means that technologies proposed to be operated directly under the control of individuals or households as part of daily life will be less well characterized by economic criteria than will intermediate production technologies. This leads to the fifth limitation of economic analyses:

5. Technologies scaled for the household or individual will be chosen and operated according to the criteria appropriate to "the level at which life is lived" (Heilbroner 1959). These criteria include social, political, religious, and familial as well as economic components.

In the past, economic development has been accompanied by a transition from traditional fuels under the direct control of individuals to fuels produced and largely consumed in centralized institutions. Such an energy transition was the inevitable result of the increased specialization of production usually accompanying economic development. The particular physical characteristics of petroleum and its long-term low price allowed this to occur. Now in contrast, such a transition seems impractical. At least, as discussed above, it seems that traditional fuels will have to be used as petroleum mimics. This means that, unlike in the past, economic development will be accompanied by a continued control of energy production and use by individuals. Such a development may be more difficult to manage than a transition to petroleum. Energy supply systems will remain more a part of daily life, with all of its "irrational" elements. Diffusion of new technology will require that fits are made between the technology and the fabric of rural society.

In spite of these mostly well-recognized problems, the bottom line of an economic analysis remains the best measure of value when a single measure is required. Furthermore, a significant amount of creative effort is being applied to improve economic measures, often with good results (Bhatia 1980). It has become increasingly clear, however, that successful and beneficial application of technology requires substantial additional information.

Indicators of Appropriateness

Few technologies require only the most easily measurable resources and provide only the most easily accountable benefits. Regardless of scale--whether a large centralized power plant or a family-sized biogas digester--some sort of extraeconomic balance must be made among the various mixes of social, environmental, and economic costs and benefits represented by alternatives. The character of the benefits and costs changes with scale, however. By their very nature, large-scale systems are part of intermediate

production--subject to economic, physical and regulatory constraints--but far from the day-to-day activities of most people. A small-scale decentralized system, in contrast, is by its nature much more a part of life at the level on which it is lived. A small-scale energy technology (SSET) such as a family biogas plant, will be a part of daily routine and have a direct effect on the quality of its owners' time and their environment. With such systems, the balancing of the difficult-to-measure characteristics of the technologies can occur without an abstract cost-benefit calculus. It can occur in the heads of the people who must live with the consequences, good and bad. It has been pointed out that this is a distinct advantage of small-scale technologies, those receiving the benefits also bear the costs and make the decisions (Holdren et al. 1980). With large-scale systems, on the other hand, this calculus must be done in some abstract manner by people not directly subject to the consequences of the technology. Moreover, the methods for performing such abstract comparisons and weighing the complicated, imperfectly understood costs and benefits occurring to different people at different times are very unsatisfactory.

This advantage of small-scale systems is accompanied by a challenge to designers and implementers who wish to make them useful in rural areas. They are challenged to understand the nature of this within-the-head calculus well enough to design technologies that have some chance of success. After the technology has taken hold, costs can be mentally weighed against benefits on site and the technology may be modified by users according to their own values and access to information and resources.

An example of this adaptation is the use of solar cookers in rural Upper Volta (UNEP 1980). The villagers modified the introduced technology to suit their own needs; in this case, to reduce the chance of food spillage at the expense of some energy efficiency. The solar cookers nevertheless had to be designed sufficiently well in the first place so that they could be adapted to the villagers' daily routine and taken seriously by them. It was necessary for the designers to understand the villagers' within-the-head calculus well enough to overcome the initial threshold of acceptability. Once this threshold was overcome, the technology was modified to optimize its utility to the villagers according to their needs and values.

The purpose of the criterion framework presented here is to tabulate the noneconomic factors that partly determine the viability of SSETs. It does not purport to model the within-the-head calculus completely, but to bring enough of the critical considerations into sufficient focus such that the technologies can be designed to overcome the implementation threshold.

The passages quoted at the outset give some guidance for determining the indicators of appropriateness that could be used in such a framework to compare the relative potential of one technology with that of another. Achieving social and environmental goals and meeting economic objectives are indicated as performance criteria in paragraphs 15 and 596, whereas resource and other "endowments" are identified as constraints. The distribution of resource exploitation--whether occurring locally in rural areas or

elsewhere--is considered one indicator of appropriateness in paragraph 297. The match of technology outputs within "existing and projected energy demands" is another noted in paragraph 298. Paragraph 301 states that organizational and institutional implications of the technologies "should receive priority attention." These guides for the creation of indicators of appropriateness are listed in Table 1.

Table 1 includes one other criterion (number 6) for a set of appropriateness indicators, the criterion of parsimony. Most people have little patience for vast amounts of information; they require easily understood, relevant, reliable, and high-density indices (Schlegel and Tarrant 1980). As it will become clear below, however, in order to provide indicators responsive to the first five guidelines in Table 1, it is necessary to develop an extensive and data-rich analytic framework, sized well in excess of any reasonable definition of parsimony. At first exposure, such a vast array of information may seem unnecessary for describing a SSET that at most, affects a few dozen people and costs a few hundred dollars. It should be remembered, however, that successful implementation of these technologies will involve hundreds of millions of people, billions of dollars, and large total energy production capacities. For example, the nine million family-sized biogas digesters reportedly installed in China must touch the lives of 50-100 million people, must have taken more than 250,000 person-years of labor to construct, and must have an aggregate energy production capacity of 3-6 gigawatts (thermal). These are large numbers by any standard. For comparison, consider the amount of data generated during the design, construction, and operation of a 6-gigawatt (thermal) electric power station (consisting of two large units). Typically, many dozens of shelf-feet are taken up with reports and, in the United States the environmental impact statement alone (along with its supporting documents) may contain thousands of pages of text and hundreds of pages of data. Large-scale energy systems such as power plants will probably always produce more total energy, but more people will be affected more directly by SSET if they become as widespread as many hope. For this reason, there is justification for spending the effort and time to collect and interpret at least as great an amount of information about SSETs as about large, centralized systems. The Chinese Biogas Manual, for example, warns that "before the pit is built there should be an exhaustive study and discussion of its size, the model to be used, the location and the materials" to avoid the "waste (of) labour, building materials and time" (van Buren 1979: p.25).

Complexification and Distillation

Thus, in order to develop indicators of appropriateness, it is necessary to go through a process of what has been called "complexification" (Suriyakumoran 1979). Complexification results in a proliferation of information about many previously unconsidered or poorly considered aspects of the situation--in this case the requirements, impacts, and outputs of SSETs. The process of complexification tends to be somewhat unselective--it offers little of direct relevance for the decision-maker in need of a few critical indicators. Complexification does offer the opportunity for modifying and

Table 1. Guidelines for Appropriateness Indicators

1. Include social and environmental as well as economic criteria.

2. Consider resource constraints.

3. Determine distribution of resource use--i.e., the locations from which resources are derived.

4. Provide a means for matching supply and demand for energy.

5. Tabulate organizational and institutional implications.

6. Ensure that the resultant indicators are small in number, easily understood, information dense, and visibly discriminating among different systems (criterion of parsimony).

Sources of numbers 1 to 5: UNIDO (1978a, 1978b).

enriching conventional analysis by developing and presenting data previously outside the boundaries of consideration. It provides legitimacy without priority.

Complexification, then, is not enough by itself. It must be followed by a process of distillation in which the data are brought to a compact, repeatable, consistent, directly relevant, and easily explainable form. Consider, for illustration, someone purchasing a stereo set in an electronics store. This person could choose merely on the basis of styling, wattage, and brand name--adequate for some purposes but indiscriminate and somewhat risky. On the other hand, the person could examine the circuit diagrams, the quality of the individual parts, the performance characteristics under a wide range of test conditions, and so on. This process would require a degree of familiarity, technical skill, and effort well beyond all but a few prospective buyers. Intermediate are those buyers who will take the time to compare alternative stereo sets on the basis of the 20 or 30 specifications published for each model. By means of these, the buyer can compare one set with another, how each set ranks along various criteria, and, by looking from set to set, understand how the various performance criteria can be traded one against another. Each set will represent a different mix and, presumably, one will represent the optimum mix for each purchaser. The wise buyer knows that these specifications do not cover everything and that, as are averages for the model line, they may vary for individual sets. Nevertheless, the specifications have been developed over the years as distillations of the technical complexification that has blossomed with the sophistication of the electronics industry. They are standardized, comparatively easily understood, and consistent.

Imagine that the prospective buyer were to enter a windmill store. Here, unfortunately, there are no agreed-upon specifications published and available for each windmill. It is difficult to compare one with another in any systematic way. In addition to the lack of technical specifications, there is a lack of agreed-upon specifications for comparing resource, social, and environmental characteristics of windmills. The lack of such specificiations makes the visit to the windmill store--or its literature search equivalent--as frustrating an exercise as comparing apples and oranges--for it entails examination of minute engineering detail, promotional hype, and sociological hypothesis.

The criterion framework to be discussed below enables one to move through complexification and distillation to a set of specifications for small-scale energy technologies. The questions to be faced are:

Complexification:	What might be important to know about SSETs? How can this information be found and organized?
Distillation:	Which seem to be the most important indicators? How can they be generated and presented in a compact, readily understood, consistent, and relevant manner?

In departure from the stereo set analogy, the specifications being pursued here are principally nontechnical. Technical specifications are also important and, in general, poorly developed for most SSETs. Yet, they are much more technology-specific than the resource, social, and environmental specifications, and there is little point in attempting to adopt standard technical specifications for all SSETs.[1]

THE FUNCTIONS OF TECHNOLOGY

The nature of technology is not easily described and, as a result, definitions are nearly as numerous as students of the subject. For our purposes, this variety of views can be spread along a single scale. At one end lies what might be called the Engineering View, according to which technology is strictly the process of materials manipulation and construction. At the other extreme lies the Social View, according to which technology encompasses "the totality of the means employed to provide objects necessary for human sustenance and comfort" (Webster's 1977), including the objects themselves, their uses, and their intellectual and social contexts (Mitcham 1978). At its extreme, the Social View of technology is difficult to separate from the entirety of culture itself (Lenk and Ropohl 1979). The appropriate technology movement is partly a pressure to move examinations of technology further toward the Social View, although not to its extreme, and away from the narrower Engineering View.

Technology, therefore, could be conceived not simply as a means to convert materials into physical artifacts, but as a means to organize physical and social resources toward achieving human purposes (Carpenter 1974). Furthermore, these purposes might better be considered as tasks or processes rather than objects. Attaining nourishment, shelter, health, education, and other human needs and desires is more accurately understood as a set of processes, not simply objects.

Taking a cue from paragraphs 15 and 296 of the UNIDO conference quoted above, one can categorize resources and tasks as physical, social, and environmental. Thus, as Figure 1 indicates, a technology can be thought of as a mechanism by which physical, social, and environmental resources are combined to accomplish a mix of physical, social, and environmental tasks.

By physical resources is meant those materials brought to the site from elsewhere--for example, metals, concrete, water, wood, and fuel. Social resources are qualities and quantities associated with human labor and organization--worker-time, levels of skills, and organizational links to the outside. Environmental resources are those found naturally and taken advantage of at the site--wind, flowing water, land, and soil. Physical tasks include

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1. Examples of technical and nontechnical specifications are presented for the case of anaerobic digestion in the second paper of this series (Santerre and Smith 1980).

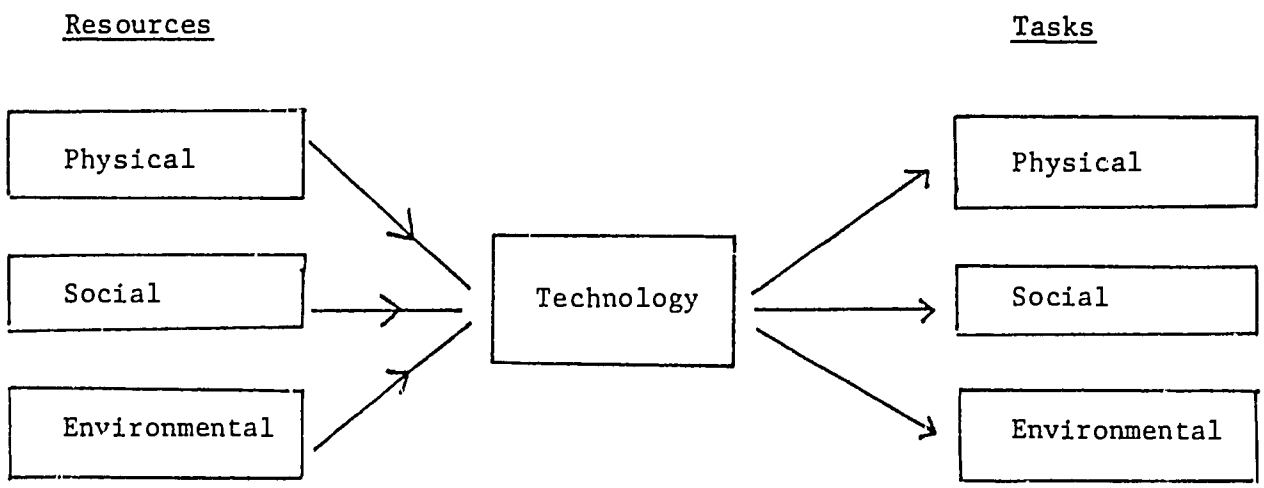

Figure 1. The Task and Resource View of Technology: Technology combines resources of various kinds to accomplish tasks of various kinds.

lifting water, cooking food, and transporting freight. Social tasks include providing jobs, increasing social cohesion, and decreasing inequity. Environmental tasks include clearing land, and stopping erosion.

In a typical economic analysis of a technology, the costs of the inputs (construction and operation) are compared with the value (benefits) of the outputs. Costs or prices provide a means to convert disparate resources into a common measure. For many social and environmental resources, however, cost estimates are inadequate or unavailable. Equally, prices and costs seem inadequate for evaluating many social and environmental tasks. Part of this difficulty is due to the nonlinearity of the social system in which real technologies exist. In practice, as a result, it is hard to separate social and environmental impacts into the categories of costs and benefits. This is particularly true in the case of small-scale technologies that operate intimately with daily life. Although the expansion into physical, social, and environmental categories provides an opportunity to explore some of this complexity, the model illustrated in Figure 1 retains the linear oversimplification. In practice, it may not be possible to distinguish clearly whether a high level of social organization for example, is a necessary resource for a community biogas plant or the result of the social task performed by the plant. The figure represents a significant improvement over conventional linear view of technology's place in society, although it does not move complete to the Social View, which would focus on the feedback and other nonlinear aspects of the interconnectedness between technology and society.

FUEL-LINKED RESOURCES AND TASKS: THE FLERT STRUCTURE

The previous discussion applies to all technologies, not just to those that produce energy; but, there are aspects of energy technologies that lend themselves to further refinement of this resource and task approach. Energy production devices do not perform tasks directly but produce an intermediate good that can be used to perform tasks only with additional devices. This good is fuel or another form of energy carrier such as mechanical motion. (Here the word "fuel" is used except where there is the chance of confusion.) Energy technology can be divided conceptually into two parts, production and use. Each part has its own set of devices and the parts are linked by fuel as shown in Figure 2. On the left side, resources are combined in various ways according to the fuel-production technology being employed. On the right, fuels are used in fuel-consuming devices to perform tasks. Figure 3 illustrates how a particular task--lifting water--can be accomplished by using one particular environmental resource, wind. Note that more than one path is available. Each path has a unique mixture of resources and tasks and technologies associated with it.

Although a number of devices can be used to perform the same task, usually the total mix of physical, social, and environmental tasks will vary from machine to machine. Wood and electrical stoves both cook, for example, but they perform quite different sets of social and environmental tasks. In turn, several fuels can sometimes be used to power one machine. A pumpset, for

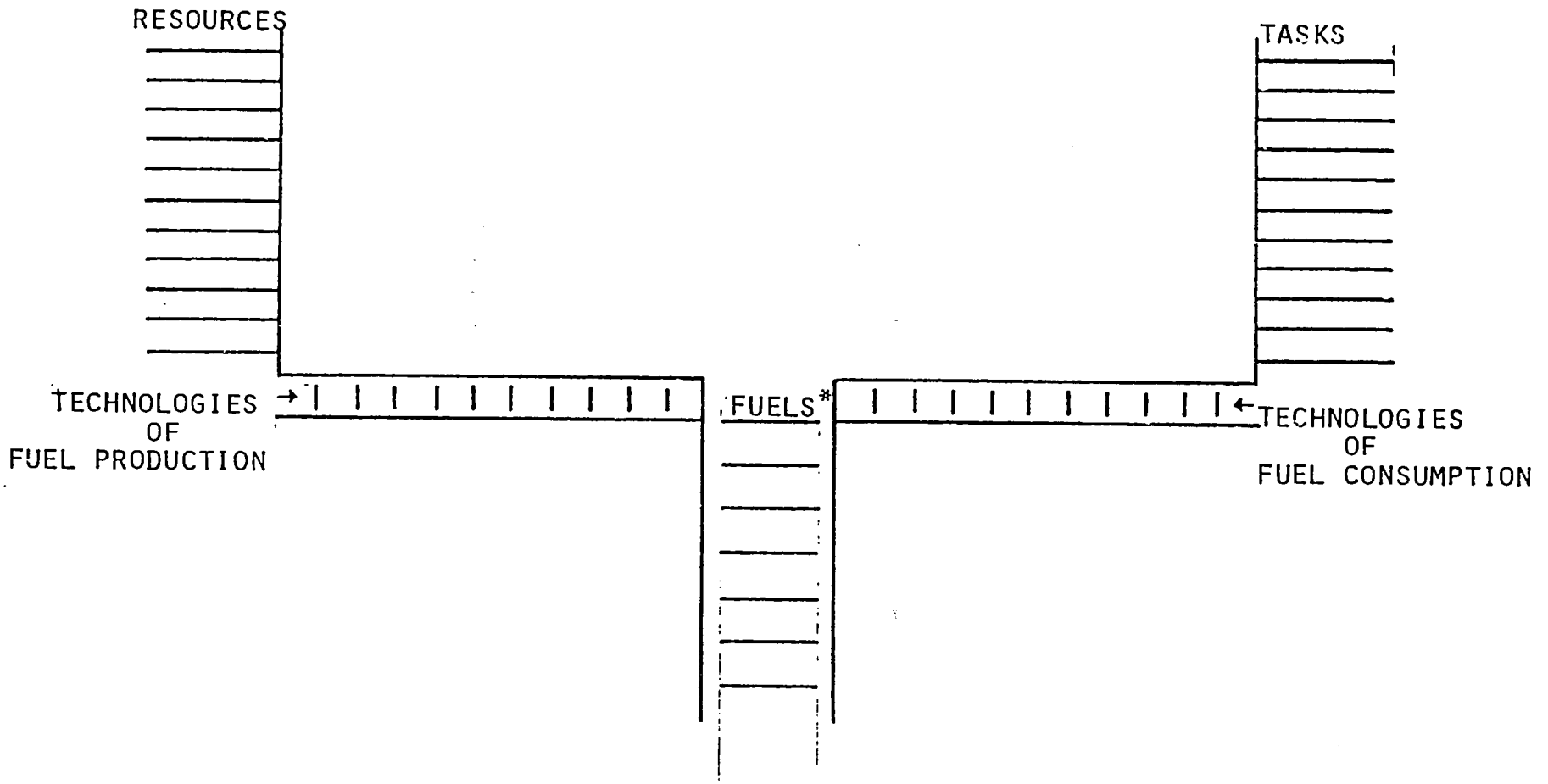

Figure 2. The FLERT Structure: Resources are used by energy production technologies to make fuel which is used in energy consumption technologies to perform tasks.

*Important non-fuel coproducts can also be listed in this column. Fertilizer from biogas digesters is an example.

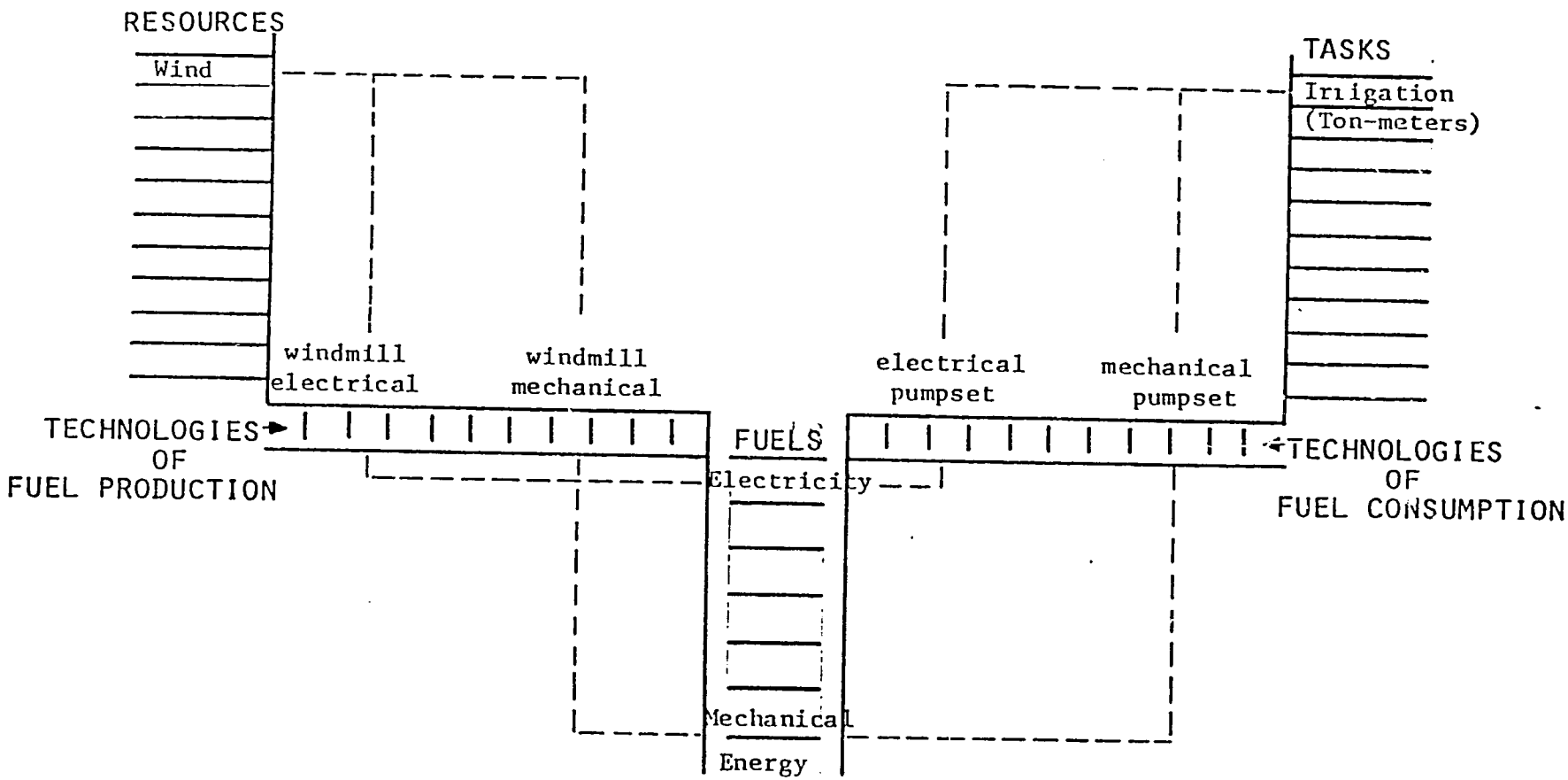

Figure 3. The FLERT Structure with Example:
Two pathways of using wind to lift water

example, might be powered by diesel oil, coconut oil, pyrolysis oil, or biogas. Each fuel can be made from numerous energy production devices in the way that electricity can be made from photovoltaic cells, windmills, or microhydro plants.

This structure is particularly adapted to examining small-scale energy production technologies where there are different ways of using resources to produce fuels and different consumption technologies for accomplishing tasks. It also helps keep in focus the necessity to perform social and environmental tasks.

An important feature of the framework illustrated in Figure 2 is that it allows the analysis to be separated into two manageable parts. Fuels provide the link between the resources and the technologies that utilize them and between the tasks and the machines that perform them. This structure retains the linearity common to many energy studies in which production and consumption are separated. Although offering a degree of analytic ease, this linearity has not usually lent itself to portrayal of the nontechnical factors that are so important in the case of SSETs. By taking into account resources and tasks, the FLERT structure broadens the analysis. It also provides a means to include social and environmental impacts, although imperfectly because of the linearity.

To achieve this complexification in a consistent and relevant manner it is necessary to specify the resources and tasks in some detail. It is also necessary to develop a significant level of detail about the fuel flows. The left side of Figure 2 has fuel output as its common denominator. The right side portrays fuel as the numerator and tasks as the denominator.

Equation 1:

Left Side		Right Side		
$\frac{\text{Resources}}{\text{Fuel Output}}$	X	$\frac{\text{Fuel Output}}{\text{Task}}$	=	$\frac{\text{Resources}}{\text{Task}}$

The coupling of tasks to resources by means of fuels can occur only if fuel flows are specified by enough relevant variables to differentiate their relative values in achieving tasks and optimizing resource use.

THE FUEL LINKAGE

For various reasons the usual indices of fuel flows are inadequate for the FLERT structure. Measuring all fuels in a common unit such as joules or metric tons of coal equivalent would be misleading because the tasks and resources associated with a particular fuel tend to be classified not according to fuel quantity but fuel form. It would not be appropriate to link a mechanical windmill with a lighting task, for example, just because the windmill's output can be measured in an energy unit such as kilowatt-hours. Of course, in theory it is possible to transform any energy form into any other form, but doing so may be impractical or very inefficient. Furthermore,

Table 3. Energy Indexing Methods

1. Physical units such as joules or kilocalories
2. International units such as metric tons of coal equivalent or barrels of oil equivalent
3. Units relevant to the major fuels commonly used in rural developing areas, such as kerosene and fuelwood
4. A fuel replacement unit by which fuels are measured against a common task

Table 2. Fuel Flow Specifications

Form	Unit	Approximate Conversion[a]
Liquid fuels	Liter kerosene-equivalent	10 kWh/LKE
Gaseous fuels	Cubic meter biogas-equivalent	5 kWh/MBE
Solid fuels	Kilogram fuelwood-equivalent	3.5 kWh/KFE
Electricity	Kilowatt-hour	-
Mechanical power	Bullock-hour equivalent	0.5 kWh/BHE
Heat	Megajoule	0.28 kWh/MJ

Temporality	Range	Measure
Frequency	Continuous-annual	Fercentage of year
Predictability	Predictable-stochastic	1, 2, 3[b]

Spatiality	Range	Measure
Flexibility	Flexible-rigid	1, 2, 3[b]
Density	High-low	MJ/liter or kW/cm^2 [c]

a. Peak power should be indicated along with energy quantity. Sources of conversion: Ehrlich et al (1977); Merrill and Gage (1978); Odend'hal (1972).

b. Subjective measures.

c. Electricity, heat, and mechanical energy.

according to the FLERT structure, such transformations are the function of the fuel-production technology and not the fuel-using technology. Thus, at the point the energy crosses the middle section in Figure 2 it goes through its final transformation into the form used to perform tasks.

The first disaggregation of energy flows, therefore, is by fuel form. It is necessary to specify only a few forms because the number of categories of fuel presently or potentially used on any scale of practical interest in the rural development world is limited. These forms are presented in Table 2. The first four (liquids, gases, solids, and electricity) require little explanation since they are easily perceived as energy carriers separate from the various machines and efficiencies of transformation. The last two (mechanical power and heat) require some discussion. Some SSETs use direct or indirect solar energy to perform tasks without going through an intermediate "fuel." A wind-powered grain grinder and a solar-powered icemaker are examples. In each case, however, it is generally possible to identify a flow of mechanical power (in the rotating shaft of the windmill) or heat (in the pipes leading from the solar collector) that separate the energy-production device from the energy-consumption device. That both of these sides of the energy technology illustrated in Figure 2 are in one location does not alter the validity of the FLERT structure. In some cases, of course, the fuel-production device may be nonexistent, and natural flows of mechanical energy or heat may be tapped. In such cases the flow across the fuel boundary in Figure 2 will be identical to the flow at the resource edge--i.e., no transformation will have occurred. Examples are the wind used to power a sailboat and the sunlight used to power a solar oven. Direct uses of traditional fuels such as dung also have this characteristic, although, of course, there are social resources involved in the collection of fuel. Draft animals, an important special case, can be regarded fuel-production technologies that convert agricultural residue, forage and ner resources into mechanical energy.

Fuel Form Indices

A unit of measure is needed for each fuel form. Table 3 shows that there are several categories of such units from which to choose. Physical units have the disadvantage of being common to all fuel forms and thus tempting people to add forms together without consideration of the greatly differentiated societal values of the various fuel forms. These enthalpic units also fail to reflect the relative energy quality of the forms. Thus, a million joules of solar heat will look the same as a million joules of oil heat according to an enthalpic unit. This is quite misleading in that these two energy flows are usually available at very different temperatures. If the oil heat is available at 800° whereas the solar heat is available at 80°C, the oil heat will be nearly five times more efficient in running a heat engine, for example. Even within one fuel form, then, energy qualities can be quite different. Between forms, they are very different. Consider the comparison of dung combustion and nuclear fission; at the atomic level the difference between them in the energy quality as measured by temperature amounts to several orders of magnitude.

International units, such as metric tons coal equivalent, have the advantage of being familiar to the broad energy and policy communities but are somewhat artificial when applied to rural energy problems. Little coal, for example, is used in rural areas. The indices of category three in Table 3 are a response to this problem.

Fuel-replacement indices are of a different type entirely from the first three listed in Table 3, which are different from one another by constant factors. The only major application of a fuel-replacement index known to us is the National Energy Statistics of India which rely on a coal-replacement index based on the substitutability of coal in the early 1960s (Government of India 1965).

Conventional energy measurement practices record coal as having approximately one-half the energy content of an identical weight of petroleum-based liquid fuel such as diesel oil. Although it is common to see all forms of energy reported as "metric tons of coal equivalent," differences between coal and another energy form such as oil are greater than the difference in their respective thermal energy content per weight of fuel. The measurement system used in India describes the energy requirements of a given task as a "coal replacement value" for a particular fuel. This measure approximates the amount of coal required to perform the same amount of work for the fuel being compared. For example, in the case of a fuel substitute for train locomotives, seven to nine times as much coal (by weight) would be needed to perform the same task as diesel fuel. This means using 3.5 to 4.5 times as much coal energy as diesel fuel energy. The comparison indicates to the Indian policy- maker that if diesel oil were to be replaced by coal for rail transport, seven to nine times more tons of coal than of oil would be needed--not just two times more as the coal equivalent measure would indicate (Chatterjee 1979).

Table 4 shows how such a fuel replacement index might be constructed for rural areas. Here, oil-based liquid fuels have been chosen as the index because they can supply energy for performing nearly all rural tasks, they have fairly uniform energy densities (40 - 45 MJ/kg), and flows of oil are of critical importance to most energy policy-making. The table illustrates how all fuels could be indexed by their value relative to that of oil-based liquids for performing rural tasks. Similarly, fuelwood, dung, or any fuel of critical interest could be used in a replacement index.

At the present, unfortunately, there are not enough data concerning the fuel substitution ratios for rural tasks. Even for such important tasks as cooking, there are only poor and contradictory data about the amount of biogas required to perform the tasks normally done with fuelwood, dung, crop residues, or kerosene (Santerre and Smith 1980). Thus, for the moment, the fuel replacement index is constrained for lack of information.

Fuel replacemet indices are also troublesome conceptually in that more than one efficiency can be assumed for the substitution ratios. In the example

Table 4. Blank Fuel Replacement Matrix

Fuel	Tasks[a]				
	Irrigate ton-meter	Illuminate 10^4 lumen-hours	Cook	Dry	Etc.
Liquids Liter kerosene Equivalents	Diesel pump set	Pressure Lamp			
Solids kg fuelwood-Equivalents	Steam pump set				
Gas m^3 biogas-Equivalents	Dual-fuel pump set	Biogas Lamp			
Electricity 1 kWh	Electric pump set	Light bulb			
Mechanical Energy 1 bullock=hour equivalent	Mechanical pump set				
Heat 1 MJ					

Note: Consistent data are surprisingly difficult to find for many of these replacements but should be easily determined for the majority of task-fuel pairs in a set of small systematic field tests (Santerre and Smith 1980).

a. For a complete list of tasks, see Table 12. Efficiencies will vary with the devices used, with variations in fuel quality, and with variations in operating conditions.

given above, it is not clear whether it is proper to compare the best (i.e., newest) coal and diesel locomotives or the average. Because both the best and the average machines change over time, should the index also change? If so, how can different years be compared? These thorny issues will not be examined further here. Although fuel-replacement indices have some advantages, it does not seem practical to apply them until these issues are settled.

As shown in Table 2, the FLERT structure relies on rural fuel equivalent measures. Chosen are the most important fuels in each category--kerosene, fuelwood, and biogas. This approach assumes that the breakdown into fuel form takes into account the relative fuel qualities; i.e., there is not a wide range of qualities within each category. Thus, the relative energy content (enthalpy) of each solid fuel, for example, is compared with a standard value for air-dried fuelwood--the most common solid fuel burned in the rural developing world. Fuelwood equivalents can be assigned accordingly to other solid fuels. It is recognized that solid fuels vary by more than the difference indicated by such a measure. Charcoal, for example, burns hotter than rice hulls, and thus a fuelwood equivalent index will distort the relative values of the two fuels to some extent. Further refinements of these fuel measures could take this distortion into account, although some of it is measured by the density index discussed below. In spite of the remaining problems, these rural fuel equivalents seem the best compromise among accuracy, data availability, theoretical validity, and understandability.

Temporality and Spatiality

More detailed specification beyond fuel form and quantity is needed in order to make and complete coupling. Because fuels are available at certain times and not others, temporal measures provide one such set of specifications. Similarly, the spatial or geographic availability of fuels vary and can be used as a set of specifications.

As mentioned in the Introduction, part of the effort going into designing fuel production technologies that modify traditional fuels is oriented to providing petroleum mimics. There is a need to supply fuels with the versatility of kerosene or other petroleum-based fuels, but made from nonpetroleum sources. Figure 4 illustrates this process schematically. Resources that can be characterized temporally and spatially are combined in the fuel-producing technologies to make fuels with different sets of such characteristics. Pyrolysis, for example, takes agricultural residues and converts them into more efficiently usable forms--solids, liquids, and gases. Tasks also can be specified according to their temporal and spatial requirements. As shown in Figure 5, fuel-using technologies may be able to modify further the temporal and spatial characteristics of fuels to match the requirements of the tasks. If not, modification of the fuel will be needed. The paths from resources to tasks in Figures 4 and 5 illustrate that one purpose of SSETs is to modify the resource characteristics (quantity, temporality, and spatiality) to meet the requirements of the tasks. This is necessary when resources in their natural form do not match these requirements.

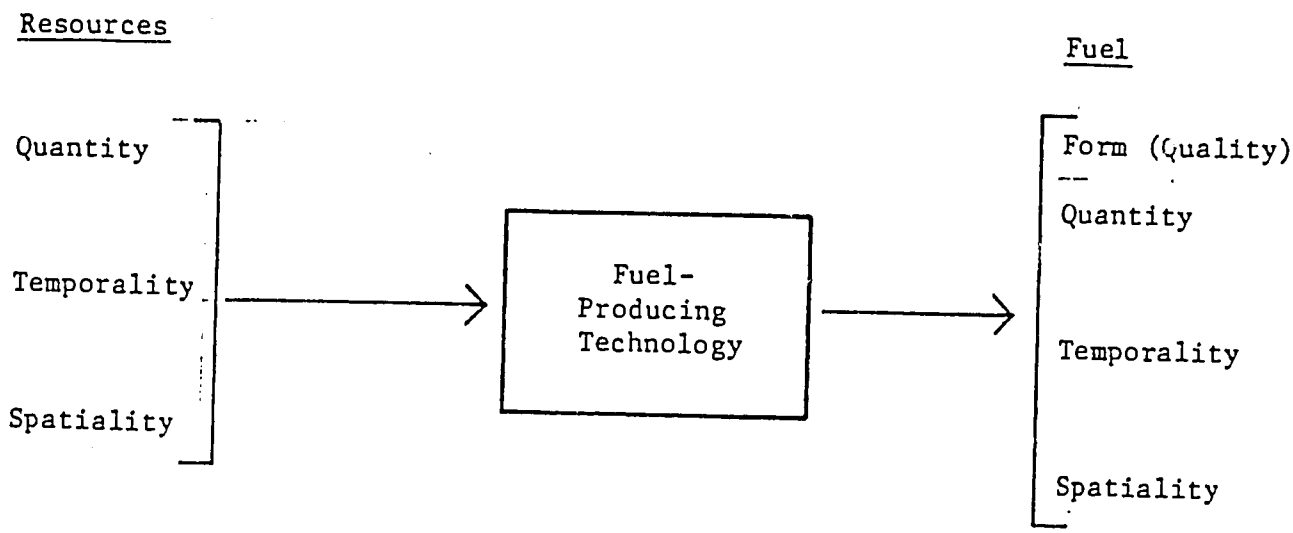

Figure 4. Resources Modification to Produce Fuel: the technology alters the mix of characteristics.

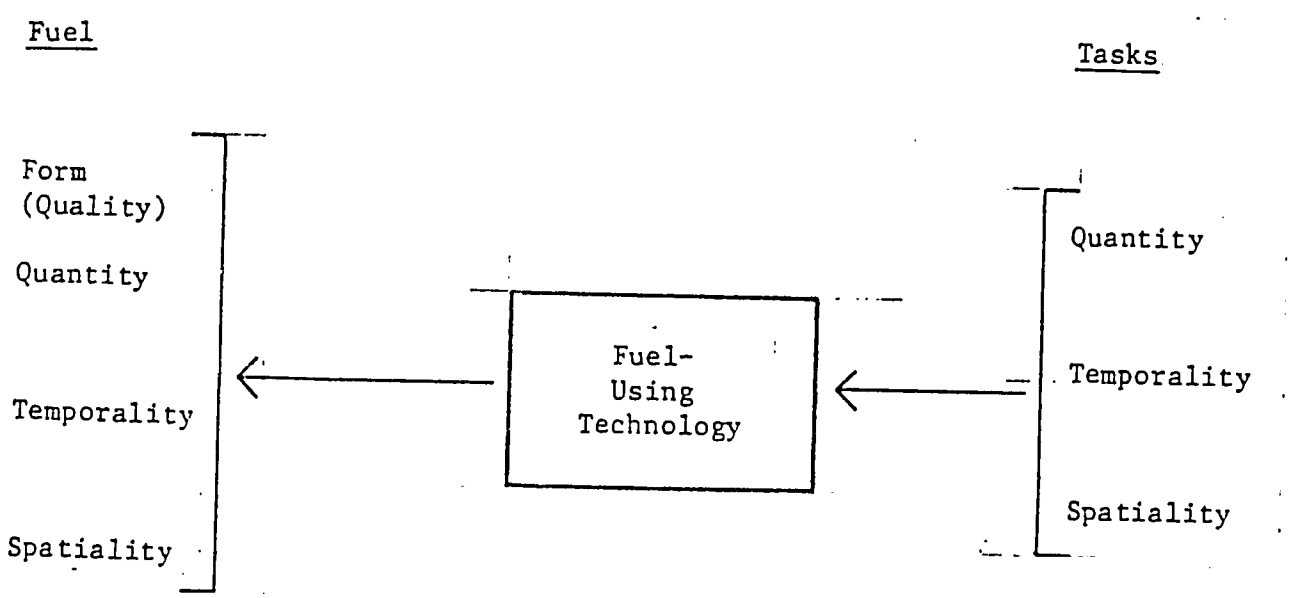

Figure 5: Fuel Implication of Tasks: Each task requires fuels with certain characteristics.

Temporality

Although a larger number of indicators of temporality might be considered (Boyd 1980), for simplicity and reasonable completeness only two are required, frequency and predictability. The first indicates for what fraction of time the fuel is available, whereas the second indicates how accurately its availability at any one time can be predicted. These are shown in Table 2. Further discussion of the rationale for these choices is found below in the section on Task Accounting.

Changing the temporal aspects of resources is often a major purpose of fuel-producing technologies. Conversion to fuel forms that can be more easily stored, for example, can extend the range of tasks performed by a resource. Figure 6 shows how a microhydro plant in combination with a small reservoir can modify the temporal characteristics of the energy resource, flowing water, to make a fuel that is more predictable and continuous. In contrast, some fuel-producing technologies actually make the temporal characteristics less advantageous. As shown in Figure 6, biogas is a fuel that is less predictable and less available than the dung from which it comes. Some of the problems of using biogas are undoubtedly due to its temporal disadvantage. There may be fewer or no tasks that fit these weakened specifications, and the other benefits of biogas--sanitation and fertilizer--may not be sufficient to overcome this disadvantage (Santerre and Smith 1980).

Spatiality

Some fuel-producing technologies can be situated essentially anywhere because the inputs are easily portable. Biogas digesters have this characteristic--dung is fairly easy to transport--but flexibility is reduced somewhat because someone must tend the plant on a fairly frequent basis. The criterion of spatiality operates at the local level; it is only applied after the availability of the resources has been determined. Obviously the biogas digester cannot operate in an area without dung supplies but it can be sited fairly flexibly within an area where supplies exist. The initial geographic restraint is common to all SSETs and, consequently, although important, is not an interesting discriminating factor. It is handled by the resource quantity criterion. What the initial spatiality measure determines is the flexibility of siting, given the existence of the necessary resources. Some fuel-producing technologies must be sited according to the location of some critical resource--best wind regime, greatest water head, for example--and cannot be placed according to the convenience of the user and the tasks to be done. Thus the first spatial indicator, as shown in Table 2, is flexibility.

Another manner in which spatial characteristics are altered lies in the ease of transport. Although many characteristics affect transportability--such as cleanliness, safety, or chemical stability--the one easiest to measure is density. Making fuels more compact is a function of many

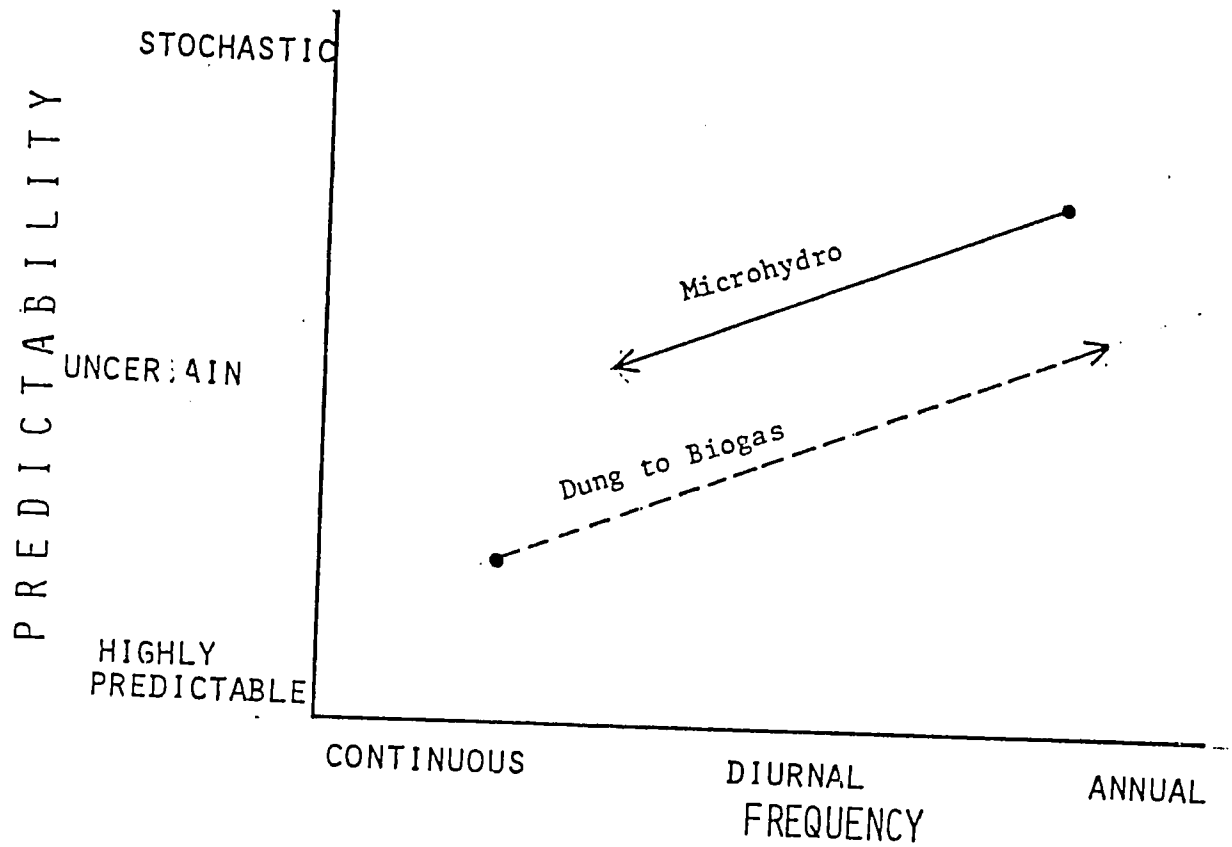

Figure 6. Measures of Temporality: Energy production technologies alter the temporal characteristics of the fuels.

fuel-producing technologies. Altering density alters spatial characteristics to a significant extent. For example, the conversion of fuelwood to charcoal allows the fuel to be shipped economically over long distances and even exported.

As shown in Table 2, density is the second spatial variable. The measure for chemical fuels is simply Megajoules (MJ) per liter. For power sources (electric, mechanized, and thermal) a measure such as kW per cm^2 might be tried. This would reflect changes in voltage,torque, and temperature--the analogs to density.

Figure 7 illustrates how three fuel-producing technologies modify the flexibility and density of fuels. Biogas digesters decrease fuel density and make the siting of fuel production more difficult. Of course, with the proper infrastructure (pipelines) this disadvantage can be overcome; nevertheless, this further negative characteristic of biogas digesters may be important to understanding their implementation problems.

Coproducts

Fuel-production technologies also produce nonfuel products. In those cases in which the material produced is truly a byproduct and relative to the fuel, of small value, its production can simply be considered one of the tasks performed by the SSET. An example would be the ashes from fuelwood combustion, which can be used as fertilizer but are not important enough to affect decisions about fuelwood use. Anaerobic digestion, on the other hand, produces an amount and quality of fertilizer that is significant. It would be inaccurate to call this fertilizer a byproduct because its value rivals that of the biogas. In the case of such coproducts, it may be appropriate to list them with the fuels, as shown in the footnote to Figure 2, to emphasize their importance and to recognize that there may be tradeoffs between the products and the coproducts (fuel and fertilizer in the case of anaerobic digestion).

RESOURCE ACCOUNTING

The physical, social and environmental resources needed to provide a particular fuel are tabulated in the FLERT approach so that different fuel-producing technologies can be compared with the resources available at various potential sites. To accomplish these comparisons it is necessary to decide not only which resources to consider but also the best measures for these resources and the accounting rules by which the resources will be tabulated. Failure to carefully consider the measures and the problems of accounting will lead to inconsistent and uncertain comparisons. In the sections below we consider first the resources and their measures.

The special attention given to the nonenergy resource requirements of fuel-producing technologies is due to the increasing realization that, in many cases, the limitations of fuel production lie in this realm and are not

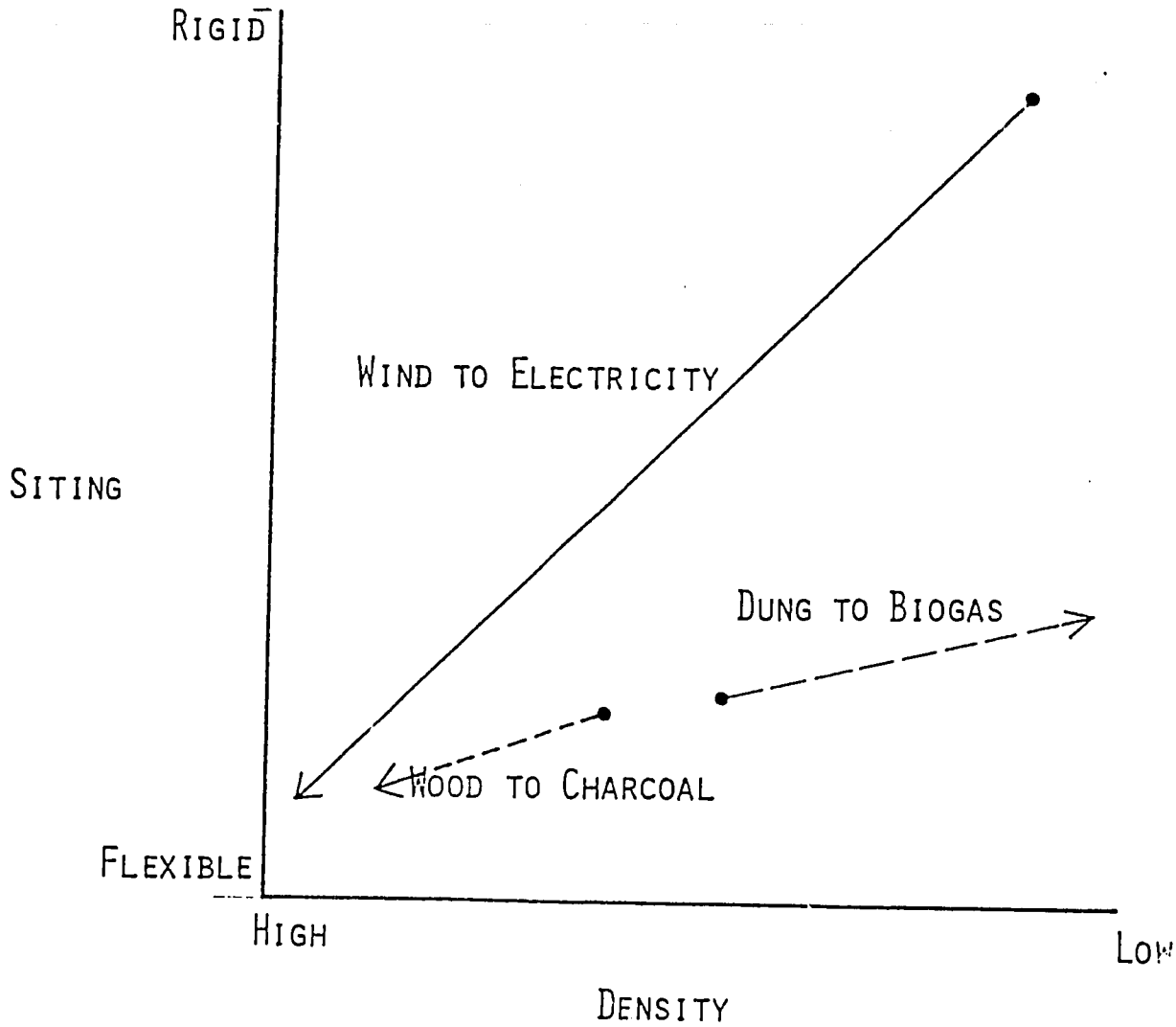

Figure 7. Measures of Spatialities: Energy production technologies alter the spatial characteristics of fuels.

accountable to a lack of energy itself. This is certainly true for SSETs in rural settings, and it is becoming generally true in the world. As the stocks of readily-accessible, high-quality fossil fuels are exhausted, the amount of nonenergy resources needed to extract lower-grade stocks or the more diffuse renewable flows is growing. Increasingly, constraints will derive from the limitation on harnessing the physical social and environmental resources needed to develop energy technologies (Erhlich et al 1977). Consequently, assessment of energy technologies should include careful tabulations of these resource requirements.

Resources and their Measures

As already suggested, it is generally easier to list physical resources than social and environmental resources. Physical resources are defined here to include materials brought to the site from elsewhere; for that reason they are much easier to identify than environmental resources which are physical materials and processes that are utilized on site, or social resources which consist of complicated and poorly understood interactions among people. Furthermore, most physical resources such as cement, metals and fuelwood are actually consumed and thus can be measured with intensive measures such as weight or volume. Many environmental and social resources, although necessary, are not actually consumed and thus are indicated by extensive measures such as level of organization and temperature. There is some awkwardness in trying to combine intensive (quantitative) indicators with extensive (qualitative) ones. Both types are important but they have to be treated somewhat differently.

The discussions of resource categories below are part of the process of complexification, which reveals a structure that would be too complicated and detailed to be practical in application. In the section on Task Accounting a similar process will be undertaken. In the section on Specification Plates which follow, an attempt is made to distill the resource and task categories down to the most important and measurable few, which still offer a realistic comparison of SSETs on the basis of physical, social and environmental resources and tasks.

Physical Resources

Interest in the physical resources required for energy production has blossomed in recent years. A number of data bases have been constructed that contain detailed information about material requirements for fuel production by large-scale technologies such as nuclear, coal, and solar-thermal centralstation electric power plants. The size and sophistication of these data bases have been increasing since their establishment in the early 1970s. Prominent examples are the Brookhaven National Laboratory/Hittman Associates Data Base (Hittman Associates 1972; Servian 1973), the Bechtel Corporation Energy Supply Model (Carusso et al. 1975, 1978), and the WELMM (Water, Energy, Land, Materials, and Manpower) Data Base of the International Institute of Applied Systems Analysis or IIASA (Grenon and Lapillone 1976). Many groups

have drawn on these data bases and, with additional data of their own generation, produced comparisons of large-scale systems on the basis of material requirements. Examples are the Energy Alternatives Study funded by the National Science Foundation (Science and Public Policy Program 1975); a comparison of solar and conventional power plants by the Jet Propulsion Lab (Caputo 1977; Smith et al. 1975); and studies done at Mitre Corporation (Mitre 1977) the U.S. Department of Energy (USDOE 1979), IIASA (Klitz 1979), Brookhaven (Moskowitz et al. 1980), and the University of California (Holdren et al. 1980). In general, these studies have concentrated on large-scale systems, although in many cases on those utilizing renewable energy sources. One incomplete study of the potential of "distributed energy systems" in California, did examine some of the physical resource requirements of SSETs suited for widespread application in industrial countries (Craig et al. 1979). Although scattered data exist in the literature, there seems to be no systematically constructued data base of this type oriented to SSETs that are usable in rural areas of developing countries. The lack of such a data base is one impetus behind the development of the FLERT approach.

To illustrate the types of physical resources that are typically included in data bases, Table 5 lists those resources found in the WELMM data base (Grenon 1979). In the second column of the table are listed the FLERT adaptations of those categories to make them more appropriate for SSETs. Because land is necessary at the site, it is considered an environmental resource in the FLERT system. Similarly, labor is a social resource. In most cases, the units of measure are straightfoward, usually mass. Fuel inputs, of course, should be tabulated in the same units as fuel outputs (see Table 2). Some of the fuels are used in the construction and ancillary operations of the fuel-producing technology, but one category is by far the largest because it measures the energy source input--e.g., dung to the biogas plant and fuelwood to the charcoal plant. Natural energy flows such as wind are classified as environmental resources in the FLERT frame whereas biofuels, which can be brought to the site, are treated as physical resources. Water necessary at the site for microhydro plants is considered an environmental resource, whereas water brought to the site is considered a physical resource; the latter includes, for example, water mixed with the dung used to charge a biogas digester. Capital is included as a potentially scarce resource here separated from the financial cost of the output fuel, which is a function of other factors besides capital.

The same temporal and spatial measures that applied to fuels can be applied to the energy resources used to make the fuels. Figures 6 and 7 illustrate how natural temporal and spatial distributions can be altered by fuel-producing technologies. Figure 8 illustrates how several natural energy flows might be arrayed on a predictability scale. There is a connection between time and space in the case of resources and tasks (the latter to be discussed below under Task Accounting). Dense fuels, which are easier to transport (spatial measure), also tend to be easier to store (temporal measure). Thus, other factors being equal, denser agricultural residues have more flexible spatial and temporal characteristics and can overcome other adverse situational and temporal distributions better than less dense material.

Table 5. Physical Resources as Classified by WELMM and FLERT

WELMM	FLERT
Water	Water (in kilograms)
Total intake	Consumed
Process consumption	(Remainder considered an environmental resource)
Cooling consumption	
Energy	Energy[a]
Electricity	Electricity
Motor fuel	Solid fuels
Process heat	Liquid fuels
Land	Land
Temporary	(An environmental resource)
Exclusive	
Manpower	Labor
General services	(A social resource)
Operating personnel	
Maintenance personnel	
Materials	Materials (in kilograms)
Aluminum	Manufactured devices
Copper	Mechanical (e.g., tractor)
Steel (total)	Electrical (e.g., generator)
Plates	Electronic (e.g., photo voltaic cells)
Pipes	Metals[b]
Reinforcing	Steel and iron
Structural	Copper
Concrete	Aluminum
Glass	Construction materials
	Cement
	Lime
	Sand
	Stone
	Glass
	Wood
	Special Requirements
	Rubber
	Tools[c]
	Chemicals
	Fertilizer
	Other (e.g., paint)
	Canvas or cloth
	Capital (in local currency)

Table 5. (continued)

WELMM = The Water, Energy, Land, Materials, and Manpower Approach of IIASA (Grenon and Lapillorne 1976; Grenon 1979). The WELMM data base has provision for many subdivisions and special additions to the above categories, but these are the most basic.

a. See Table 2 for units.

b. For some systems it may be valuable to separate fabricated metal parts (e.g., nuts, bolts, and wire) from sheet metal and other simple forms.

c. Tools often can be shared with other activities besides being used for constructing, operating, and maintaining the energy production technology.

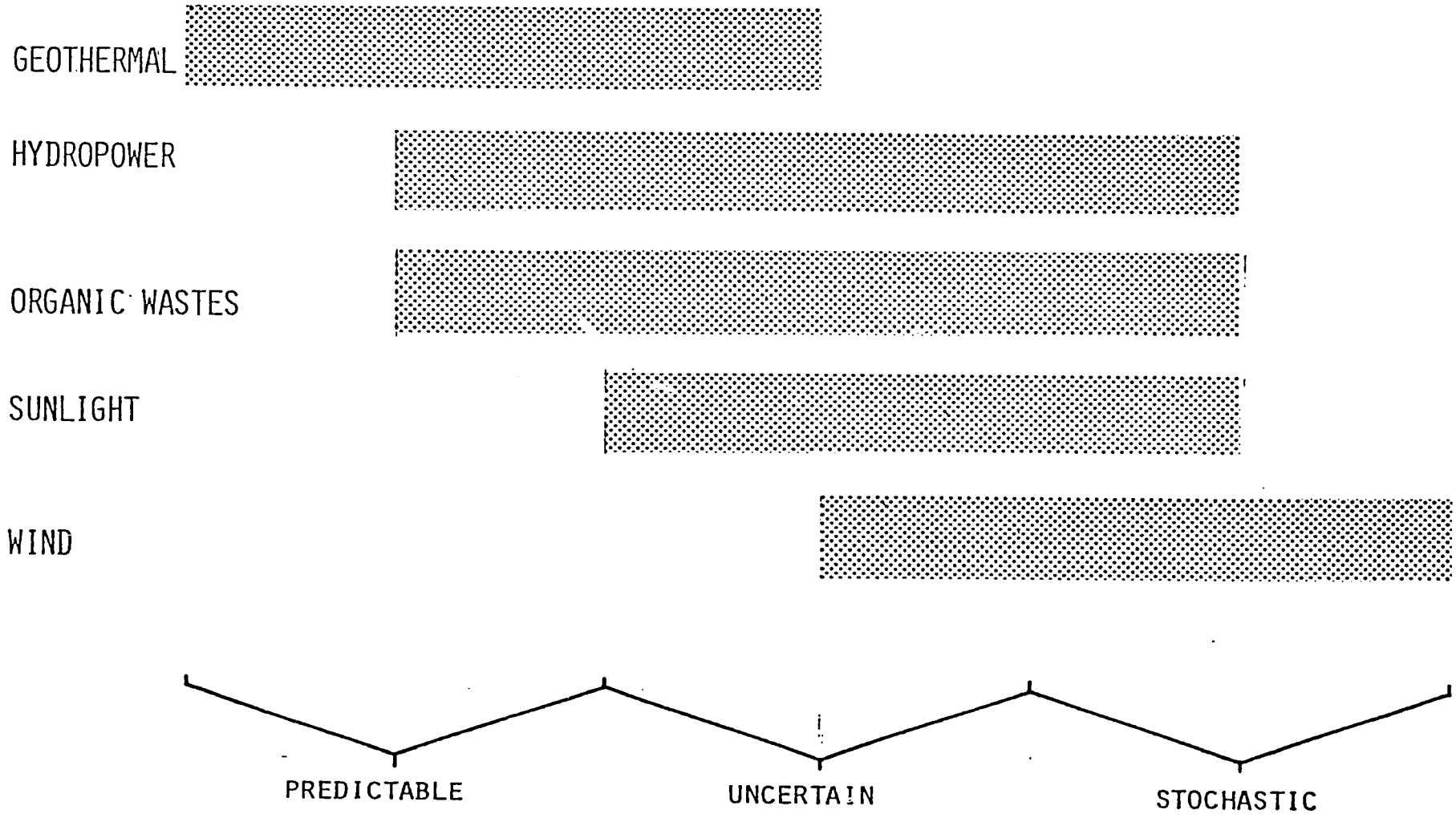

Figure 8. Energy resource predictability. The predictability of the variation of energy sources is different. This measure focuses on the predictability not on the variation, which, as in the case of the diurnal cycle, might be quite predictable or not, as is the weather.

For the nonenergy resources required by fuel-producing technologies, the principal temporal distribution is related to the phases of technological life--that is, construction and operation. The principal spatial distribution chosen for FLERT is the distinction between resources derived from the village and those that must be brought from outside. These and other temporal and spatial distinctions are discussed below under Rules of Accounting.

Social Resources

Social resources are more difficult to identify than physical resources and much more difficult to quantify. Table 6 illustrates several categories of social resource that might be considered relevant to SSETs. Resources listed under labor are straightforward and mostly intensive. A fuel-producing technology requires a certain number of labor-hours within various skill categories for each unit of fuel produced. Further division could occur on the basis of whether the labor-hours are manhours, womanhours, or childhours. It is likely to be difficult, however, to specify that a labor requirement must be fulfilled by men, women or children, only that it could be. Thus, it might be useful to employ some measure of the demographic diversification potential as well as the skill levels. Property rights arrangements, especially those involving land, are important for fuel-producing technologies, such as biomass, with significant land requirements. Conceivably, the success of some SSETs may also depend on the existence of a significant monetary economy in the local setting. Certain types of community-based SSETs, for example, may depend on monetary payments from customers to the central fuel-producing operation.

Some of the most attractive potential SSETs, from the technical and economic points of view, are those designed for operation at community scale. Yet, the results of such efforts have been mixed, and failures are often attributed to the lack of the village social organization necessary to operate the systems (Bhatia 1980). Thus, it might be advantageous to be able to estimate the level of village organization in advance such that SSETs could be located according to the level of organization required. In this sense, village organization is a resource needed for SSETs. Success is just as dependent on the existence of the required amount of organization as it is on the required amount of wind or other, more obvious, resources. Table 7, lists some of the separable characteristics within the broader category of community organization. Determination of which of these are most important and development of quantitative indicators await further research (Lilo and Abad 1980).

Although the measures shown in Tables 6 and 7 for the social resources related to the economy, property rights, community organization, and culture are extensive, there are reasons to believe that intensive measures may also be appropriate in some cases. It has been stated, for example, that community organization is something that can be consumed--i.e. that is has the property of intensive not extensive resources (Harahap et al. 1979). This is possible

Table 6. Classes of Social Resources with Examples

Class	Unit of Measure
Labor	
Professional	Labor (in hours)
Skilled	Labor (in hours)
Unskilled (semi-skilled)	Labor (in hours)
New types of jobs	Number
Demographic diversification potential	(See text)
Economy--monetary or barter	Fraction of local income (see Table 7)
Land tenure (property rights)	
Density	Hectares/capita
Fractionization	Hectares/landowner
Proportion of population landless	Percentage
Culture--taboos	Fraction of population observing taboo (see Table 7)
Community	(See Table 7)

Table 7. Community Social Resources

Community Characteristic	High	Low
Organized along cooperative and consensual lines, or highly stratified?	Cooperative	Stratified
Division of labor (occupational specialization, number of distinct economic, cultural, political, and social roles and skills) simple or complex?	Complex	Simple
Institutional diversity (the range of commercial, educational, political, religious, etc., activities and organizations) high or low?	High	Low
Integrated into a wider intervillage or urban system, or remote and isolated?	Integrated	Isolated
Economic, social, and political influence widely shared, or highly concentrated in the hands of a few individuals or groups?	Shared	Concentrated
Ethnic, linguistic, and religious composition highly diverse, or relatively homogeneous?	Homogeneous	Diverse
Physical access to markets and market information well developed, or intermittent and unreliable?	Good	Poor
Political relationships with central authority friendly and cooperative, or strained and competitive?	Cooperative	Competitive

Note: In general, the probability of successful and sustained utilization increase to the left of the range for technologies requiring greater degrees of community organization. This table was developed by Charles S. Schlegel (Smith et al 1980 p. 3).

if the entire available organizational capacity of a village is taken up by the operation of a community-based SSET. As in the case of other intensive resources, the organizational resource is then unavailable for other uses. It means the social resource may be intermediate between intensive and truly extensive resources such as temperature, which are not directly depleted. Development of intensive social indicators may be a worthwhile research direction.

Environmental Resources

The concept of environmental services is becoming more clearly defined and accepted for describing the global environmental situation. It is apparent that important functions are served by natural systems such as the climate, the soil, the hydrologic cycle, aquatic life, and forests. These functions can be essential to the physical well-being of humanity or important inputs into the economy. In most cases their replacement by human-mediated systems would be impossible, expensive, or very awkward. These facts are painfully apparent in the rural areas of the developing world, where the services performed by the soil, the forests and the streams and rivers are an intimate part of daily life. Few doubt that the preservation of the natural ecosystems that provide these services is essential. The ecosystems are no less essential to the industrialized world, but their perceived remoteness from daily life has lead to a disregard for their importance (SCEP 1970; Ehrlich et al. 1981).

It is quite appropriate, therefore, to speak of these services as necessary environmental resources although to quantify them is somewhat difficult. A distinction is necessary between environmental resources and environmental impacts. The former are the environmental characteristics (intensive and extensive) needed by an SSET, whereas the latter are the results of the construction and operation of the SSETs. Environmental characteristics are the impacts of the environment on the technology; in contrast, environmental impacts are the impacts of the technology on the environment. Of course, it would be possible to invert environmental impacts into a resource framework. One could, for example, regard emissions of air pollutants as using the environmental resource of clean air and consider occupational diseases as a demand on the health resource of the population. The absorption capacity of the environment could be identified as a resource such that many environmental impacts would be measured as a depletion of that resource. This inversion may be worth pursuing in a future refinement of the FLERT structure, but for the moment only the more direct environmental resources will be tabulated. This does not mean that environmental damage is completely ignored. Excess demand on the intensive environmental resources, such as water supplies, or on extensive resources that can be damaged, such as the soil, are important indicators of environmental impact. Unless all environmental impacts are inverted into the resource framework, however, the FLERT approach, like all other resource and economic analyses, will have to be accompanied by separate environmental impact studies.

The list of environmental resources found in Table 8, therefore, should be considered partial. Further elaboration may be required.

Table 8. Environmental Resources

Resource	Conversion[a]	Measure		Variation[b]	
		Average			
Climate					
Temperature		Annual		Month	Year
Rainfall		Annual		Month	Year
Natural Energy Flows					
Insolation	24 langleys	Annual	MJ/m^2	Month	Year
Wind	c	Annual	BHE/m^2	Month	Year
Flowing water (energy)	1.8×10^5 kg-m	Annual	BHE	Month	Year
Other uses of water		Annual	tons	Month	Year
Land					
Area			Hectare		
Slope			Maximum allowable		
Soil					
Type			Range of soils usable		
Nutrients consumed			Mass		
Absorptive Capacity of the Environment					
Air					
Water					
Land					

a. Sources: Ehrlich et al. (1977); Merrill and Gage (1978).

b. Average in high and low months and high and low years in last decade.

c. $BHE/m^2 = (4.1 \times 10^{-6})(V^3)(\text{hours})$ where V is constant.

RULES OF ACCOUNTING

Accounting schemes provide the framework by which the relative resource positions (inputs and outputs) of different activities can be compared. The choice of accounting scheme can be as crucial as the choice of the types of resources to be compared. The most familiar accounting schemes are financial ones, and financial accountants have developed standard approaches that generally allow a consistent and reliable comparision to be made of the relative financial positions of various activities. Nevertheless, entirely legal but sufficiently inconsistent accounting schemes have been used in such a way as to prevent meaningful comparisons. The oil companies are notorious for this practice, for example (Sampson 1975).

Careful attention to the choice of accounting rules is even more important when nonfinancial resources are to be tabulated. This is because nonfinancial resource accounting must consider explicitly some factors that are fairly simply handled in financial accounts. These differences, which will be touched upon in the sections below, stem basically from the assumption in financial accounts that price reflects value at each transfer point. The amount of a debit or credit contains all the information relevant to an account of the activities that went into creating the credit or debit (Smith 1979).

Resource accounting is what might be called secondary accounting in the sense that it attempts to tabulate all of the separate chains of resources in units commensurate with each type of resource and, unlike financial accounting, does not determine a bottom line in which the values of all items are reflected. Secondary accounting is pursued because there is suspicion that financial accounting does not properly take into consideration the true societal values of many resources. Secondary accounting is also a necessary part of specialized techniques that require data about resource flows. Net energy analysis and risk analysis are examples of these techniques.

The resource data bases listed above in the section on physical resources are examples of major secondary accounting schemes. To maintain consistency in resource accounts from technology to technology, it is necessary to adhere carefully to a series of accounting rules. Unfortunately, failure to do this has led to unnecessary confusion in both technical and policy discussions. The recent debates over net energy and comparative risk are examples of how failure to do accounting correctly can lead to misinformation (Holdren et al. 1979). In addition, strict adherence to accounting rules allows resources flows to be divided finely enough so that categories of special interest to society can be developed. In the discussion of accounting rules that follow these opportunities will be mentioned.

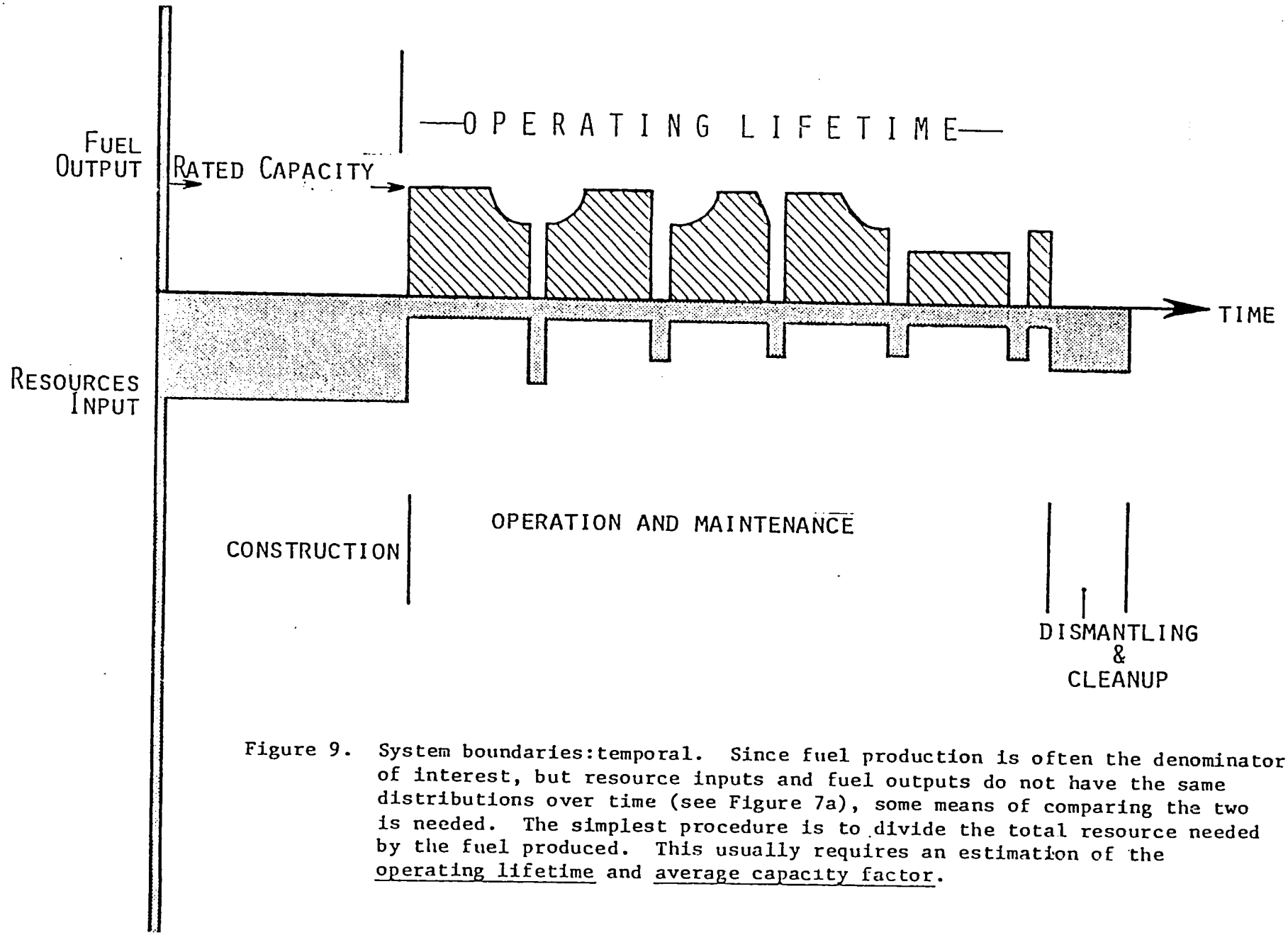

Figure 9. System boundaries:temporal. Since fuel production is often the denominator of interest, but resource inputs and fuel outputs do not have the same distributions over time (see Figure 7a), some means of comparing the two is needed. The simplest procedure is to divide the total resource needed by the fuel produced. This usually requires an estimation of the operating lifetime and average capacity factor.

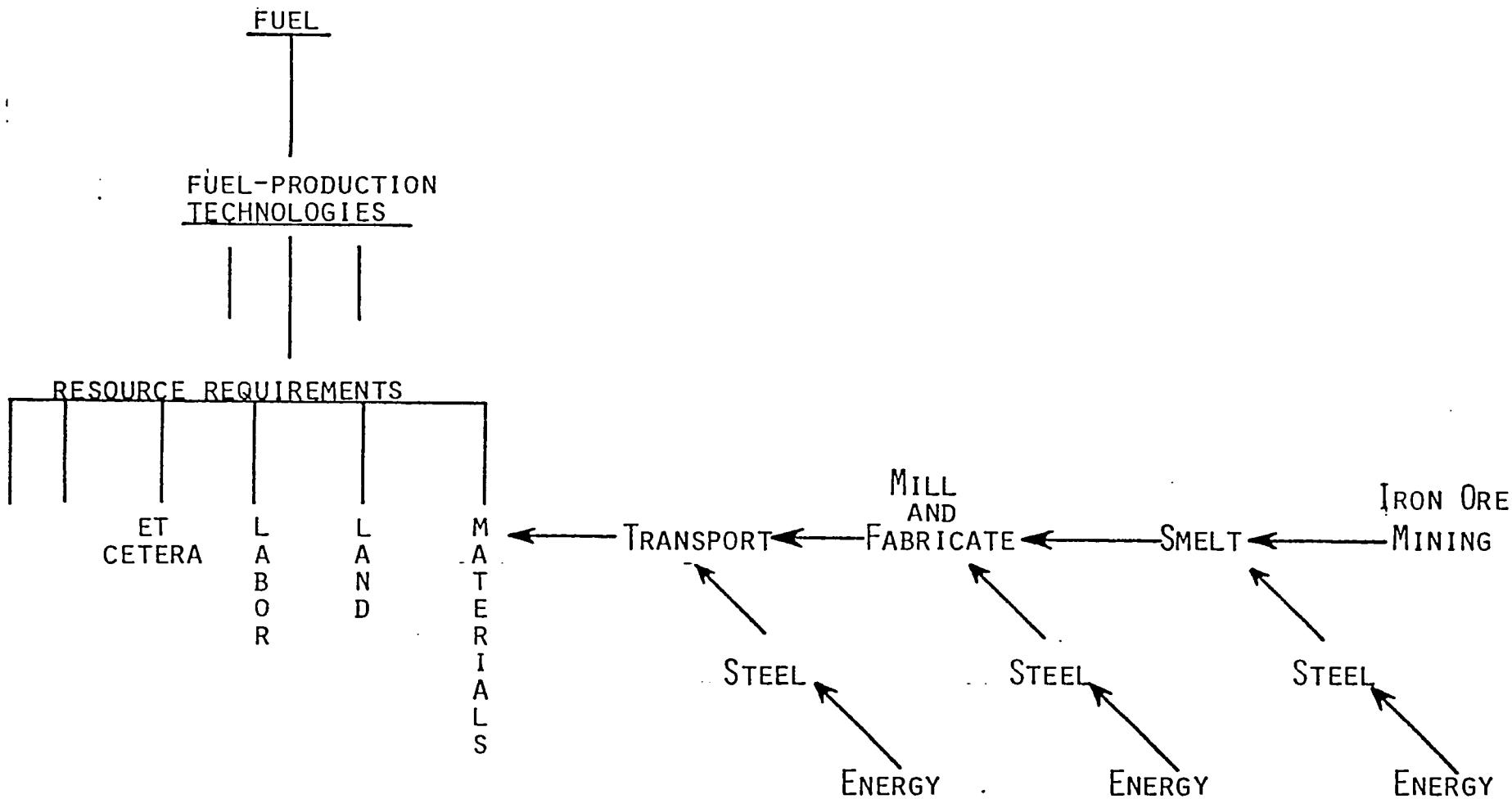

Figure 10. Resource Chains: Process schematic showing sample resources required to supply materials input to a small-scale energy technology. The total resource requirements for an energy technology include not only those actually used in the construction and operation but also those used to provide the infrastructure that supplies the primary resources. These requirements can be determined either by a process analysis as illustrated here or, where the data are available, by a physical input-output analysis.

Rule 1: System boundaries must be specified

Energy technologies are conventionally divided into subsystems, that can be fit together to form the entire system without gaps or overlaps. The WELMM method, for example divides fuel-production systems into five stages--harvesting, upgrading, transportation, conversion, and managing wastes. These particular categories may not be ideal for some SSETs but they do illustrate the principle. Important in the FLERT approach would be the addition of fuel distribution and use. The application of the FLERT approach to biogas (Santerre and Smith 1980), illustrates how a particular SSET might be divided into subsystems. Attempts to compare fuel-production technologies without a full consideration of the various fuel-cycle steps will be misleading. The potential for mistakes comes because fuel-cycle steps often exist at different geographical sites and it is easy to forget that a pyrolysis plant, for example, is linked intimately with the agricultural residue collection system.

In addition to this spatial boundary issue, there is a simple temporal distinction between construction, operation and dismantling. Resources will be needed for all these phases and thus each phase must be taken into account. Table 9 illustrates these simple spatial and temporal distinctions and the resultant categories of resource requirements. Resources needed for dismantling will usually be mostly unknown and of considerably less concern to most decision-makers.

To be consistent, the resources in each category should be listed in reference to a common denominator. For fuel-production systems there are two principal denominators, energy production and capacity (power or energy production capability per unit of time). In the case of capacity, only the construction resources are usually of interest. In the case of energy production, it is necessary to combine construction and dismantling resources with operating resources to determine total resources per unit of fuel produced. Figure 9 illustrates how resources might be invested during the lifecycle of an SSET. To use fuel production as a common denominator it is necessary to add up all the fuel expected to be produced and divided into the total resources used. This is equivalent to prorating the construction and dismantling resources over the operating lifetime of the plant. For this calculation, two additional parameters are critical, plant life expectancy and capacity factor. In order to do the prorating, it is necessary to estimate both how long the facility will operate and also at what fraction of its rated capacity it will produce fuel. These two parameters are among the most crucial in comparisons of SSETs (Santerre and Smith 1980).

There are also important and spatial boundaries that are more subtle and difficult to take into account. In addition to the direct resources used to build and operate an energy fuel-production technology, resources are used in making the materials to construct the facility. Figure 10 illustrates how numerous chains of activities are connected to each primary fuel-cycle step. Steel is used to make the shovel that is used to mine the coal that is used to smelt the iron ore needed to make the steel used to make the truck to carry the digester to the town near the village. Without a careful delineation of the system boundaries, it is not clear how far back along these various chains the

Table 9. Simple Spatial and Temporal Boundaries

	Activity		
Fuel Cycle Step	Construct	Operate	Dismantle
Harvest			
Upgrade			
Transport			
Convert			
Manage wastes or coproducts			
Transmit			
Use			

Note: Resources are required for each activity at each step. Resources can be tabulated per unit of energy produced (tons of cement per 10,000 kWh) or per unit capacity (tons of cement per kW).

accounts should proceed.

This problem can be solved in several ways adapted from economic and financial analyses. They include:

1. Process analysis, in which each chain is followed back to a set of natural boundaries. Examples of natural boundaries are the points at which the material comes from the ground or enters the country. Unfortunately, there are so many chains upon chains that process analysis cannot be realistically undertaken all the way to natural boundaries except in very simple economies (Perry et al. 1979).

2. Input-output analysis, in which calculation can be made of the incremental changes in all sectors of the economy as a result of changes in one sector. Large input-output matrices are available in many countries, and regional and local versions are also common. Most of these national matrices are tabulated in monetary units, which can be converted to resource units only with uncertainty. A few physical input-output tables also exist (Nasar-O'Brien 1979). Unfortunately, there are problems with this approach--data are often classified in awkward categories and are out of date, to mention two--and some methodological questions.

3. Hybrid approach, in which a compromise is made between the conceptual and data limitations of the process and input-output approaches. The hybrid approach uses process analysis to measure the resource requirements of the major fuel-cycle steps, thereby eliminating the problems caused by the inexactness and data obsolescence of intput-output analysis. The resource requirements of side chains are then "captured" by input-output analysis, eliminating the impossible task of following hundreds of process chains back to natural boundaries.

4. Artificial boundaries, or boundaries drawn somewhat in advance of the natural ones in order to save time and effort. Because the contribution from each step that is far back along a chain is comparatively small, there is some point where inclusion of additional steps would not improve the answer by more than a few percentage points and probably less than the uncertainty in the numbers as a whole. The problem with these artificial boundaries is that they have often been somewhat arbitrarily applied. When this happens, it is not clear how comparable one analysis is with the next (Holdren et al. 1979; Smith 1980c).

It is tempting to use the artificial boundary method for FLERT for the reason that the best method, the hybrid, requires sophisticated and largely unavailable local and regional input-output matrices. It turns out, however, that there is an additional advantage to using the artificial boundary approach. If artificial boundaries are drawn geographically around the village in which the SSET is to be installed, some important additional information about resource requirements can be gained. Paragraph 297 of the UNIDO document quoted at the outset recommends that the degree to which local resources are utilized be a measure of appropriateness. By drawing the boundary carefully

around the village as shown in Figure 11, it should be possible to determine the extent of resource activity within the village by means of simple process analysis and to treat all other resource requirements as imports. It could indicate, for example, how much labor would be needed in the village if a number of biogas digesters were to be installed. Wider and wider boundaries could be drawn to determine the amount of labor required locally, regionally, and nationally. The same technique could show the national import repercussions of a large commitment to a particular SSET. Such information would be of interest to many policy-makers. In practice drawing such boundaries will also be somewhat arbitrary, for there is no standard village in reality.

Greater sophistication in drawing temporal boundaries is needed because of the basic difference between financial and resource accounting; resource accounting has no temporal chauvinism as does financial accounting. A financial account need take into consideration only two things about a debit or a credit--its magnitude and date. The concept of present value allows the accountant to fold all possible magnitudes and dates (past and future) into a single equivalent debit or credit. There is no equivalent rule for nonfinancial resources that would permit the relationship of tons of concrete at different times to be uniformly determined and a combinational measure easily calculated (Smith 1979). The only convenient approach is to treat all dates as equal; but this solution is not entirely satisfactory because it is often better to postpone payment for resource as well as financial reasons. In other circumstances, biomass resource, for example, it may be better to pay evenly over time rather than in lump sums. Thus, temporal distribution is important, but resource accounting offers no way to collapse a temporal distribution into a single measure.

Rule 2: Technologies to be compared must have comparable outturns

It is important to compare alternative SSETs on an equal basis. As discussed above in the section on fuel linkage, it would be preferable to compare only SSETs that perform comparable tasks. This is impractical because the mix of social, physical, and environmental resources is usually quite different for different SSETs. Also technologies such as anaerobic digesters have coproducts rivaling the fuel output in total value. As a compromise, it is best to make a comparison on the basis of the output of the same fuel form. A gallon of gasoline may have the same thermal energy content as 37 kilowatt-hours of electricity, but there is little direct overlap in the tasks to which these important fuels are put. Comparing them is somewhat akin to comparing meat and potatoes: Both are foods, but no single measure can be used to place them on a scale that would mark their relative value as foods. It is not true to say that a kilogram of 2,000 calories of each are the same (Smith 1980b). Similarly, different fuels must be treated separately. Comparisons should be confined as much as possible to SSETs that produce the same sort of fuel. The units shown in Table 2 might be used. Figure 12 illustrates this idea in the case of a few of the resources needed to make electricity with a

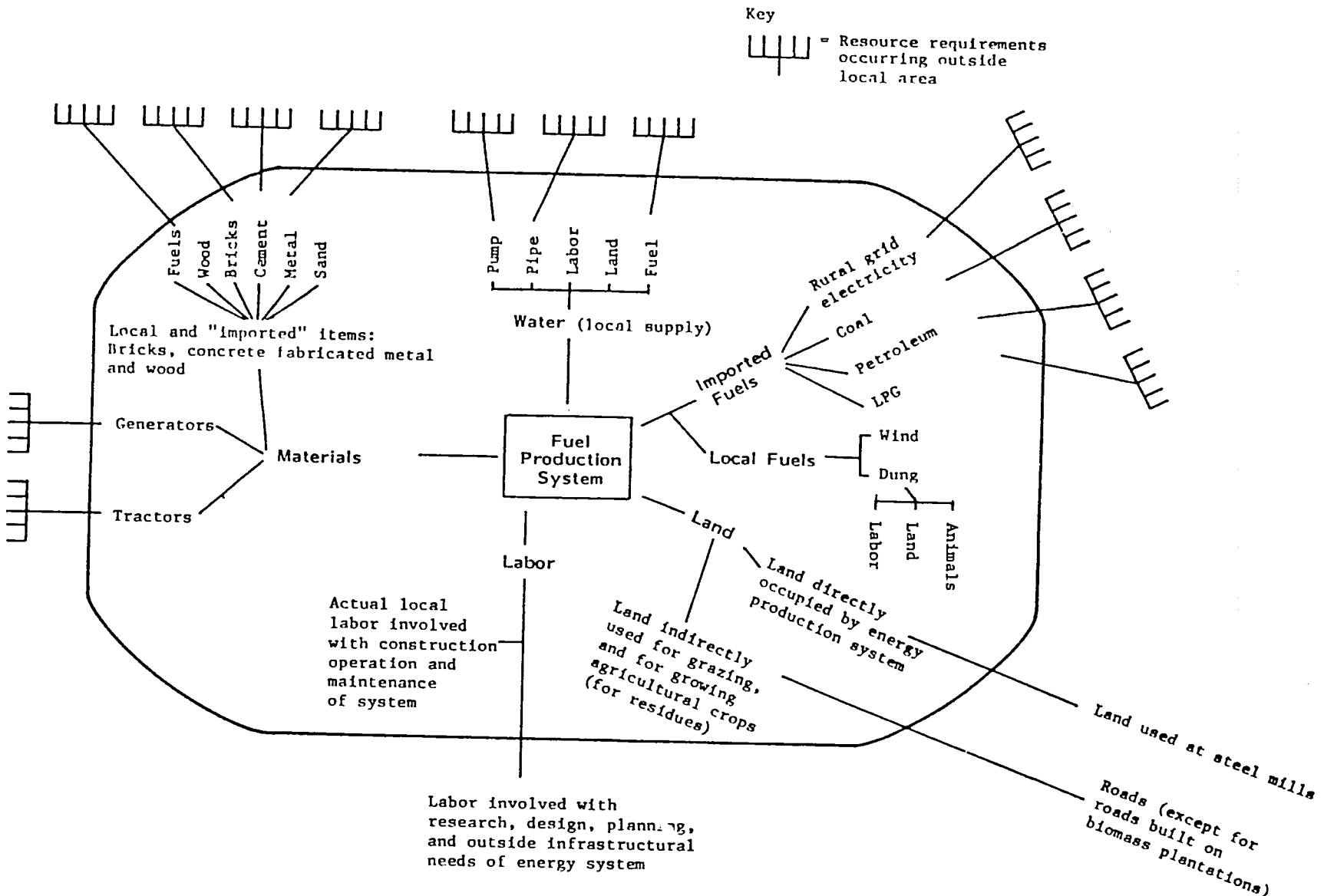

Figure 11. Systems boundaries: geographical. It is important to specify the systems boundaries in a resource accounting. Here, the boundaries are specified in such a way so as to enumerate in detail only those requirements at the village level. (The Figure is illustrative and does not cover all resources.)

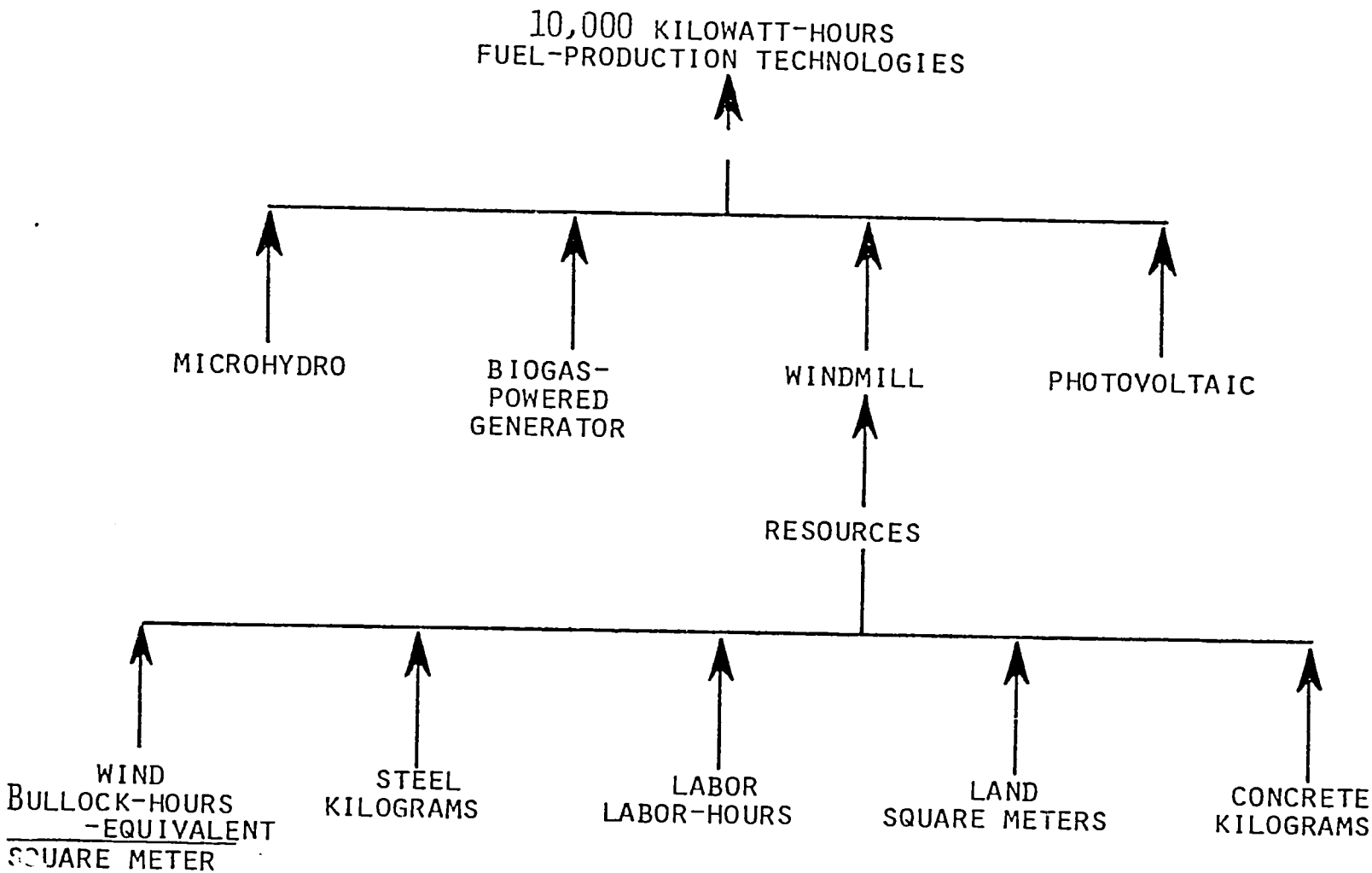

Figure 12. Resource requirements should be tabulated on the basis of producing a standard amount of fuel. Direct comparison should be confined to technologies producing fuels of the same form.

windmill.

Rule 3: Gross and net requirements should not be confused.

Another problem is created by the large number of activity chains surrounding the construction and operation of an SSET. It is sometimes difficult to be sure that everything has been counted but not double-counted. In a simple example, one would not add the kilograms of cement to the kilograms of concrete because some of the latter consists of the former. Nevertheless, some more subtle and easily made errors of this type are made.

Consider the labor requirements of an SSET. Should one also count the resources needed to support the labor resource--the education, training, housing, food for the family, and so forth. Here the criterion of net change can be applied. People are normally not "created" (or even moved into a village) to work at an SSET. They would be there whether the facility was built or not. Thus, although special training for operators of the SSET might be an appropriate resource to include, the other inputs (education, housing, etc.) needed to raise and sustain the labor force would not be appropriate. The training occurs because of the SSET--a net change--but the other support would occur anyway and, while no less necessary, its occurrence is not contingent upon the establishment of the facility.

The most difficult problem in determining net requirements results from the situation, common in rural areas, that resources to be used in a new SSET have alternative uses before the SSET exists. The dung to be used in a biogas digester may now be used as fertilizer, cooking fuel, and plaster, for example. Its procurement for a digester can thus disrupt the performance of tasks and the resource requirements in other locations of the village.

It might be possible to apply a value-added approach to this problem similar to the way that net national product is calculated. For practical application, on the other hand, it is probably best to solve the problem by treating the status quo as an alternative. In other words, the present fuel-production systems (such as those using dung) should be identified and subjected to the same FLERT procedure. Then by comparison with the resource and task characteristics of the proposed SSET, the changes can be determined. Looking at the SSET alone indicates the gross requirements--which are important for determining the overall adequacy of resources. Comparison with the status quo alternative indicates what new resources would be needed (or freed) and what new tasks would be performed (or old ones left undone). There are the net impacts of an SSET. The result of such an analysis is an understanding of the competition of various possible uses of the same set of resources.

Rule 4: Numerical information should be presented in ways that indicate the degree of uncertainty

It is unfortunately common in this field of study to see data

presented with four, five or even eight places of accuracy. Few field engineering, economic, or social data are so accurate. In most cases two or three places of accuracy are all that can be justified, and in many cases even two places (1 percent accuracy) are probably unrealistic. Exaggeration of accuracy is misleading and can lead to distinctions unsupported by the data.

If possible it is useful to identify the principal causes of uncertainty. Readers can then decide for themselves the degree of confidence they should place in the figures. One of the major causes of uncertainty is unspecified assumptions. In many cases a researcher performs calculation based partly on measured values and partly on assumptions. This mixture is perfectly acceptable as long as the researcher's assumptions are stated. What often happens, however, is that another researcher cites the values without using consistent assumptions or even reporting the assumptions used by the first researcher. One of the benefits of such a structure as FLERT is that it offers a consistent set of assumptions and accounting rules.

Table 10 summarizes the important accounting rules for assuring consistency and practicality of resource accounting.

TASK ACCOUNTING

Many observers of the energy scene have argued for tabulation of energy services (or tasks) rather than simple measure of energy flows:

> What one should examine, then, is not final energy, not even useful energy, but energy services--i.e., legible books, human thermal comfort, transportation. These services are not a mode of energy; they do not obey a law of conservation; but they do engage energy (Hafele 1980: p. 720).

This shift in emphasis is important because,

> a thriving economy and a materially rewarding life are dependent not on the given quantity of energy consumed but on the <u>services</u> or <u>benefits</u> that are derived from that consumption (Sant 1979: p.4).

Such services as a legible, i.e. properly lighted book are easier to conceptualize than to measure directly:

> An energy service may be defined as a measure of the service provided to ultimate consumers by their own use of energy in any of its forms.... Energy services are measured in units of work, of heat at various temperatures, etc., but these quantities are merely surrogates for measures of the satisfaction experienced when human wants are fulfilled via the direct use of energy (Reister and Devine 1979: p.1).

Table 10. Accounting Rules

System Boundaries

1. Small-scale energy technologies can be divided by subsystems into

   a. fuel-cycle steps, and
   b. phases of operation.

2. Resources can be tabulated per unit of

   a. capacity, and
   b. energy production.

3. Combining resources at every phase requires estimates of

   a. capacity factor, and
   b. lifetime of facility.

4. Artificial boundaries should be drawn around the village so that resources required at the local level can be differentiated.

Comparable Outputs

Direct comparison should be confined to technologies producing similar fuels or tasks.

Gross and New Requirements

1. Care should be taken to avoid double counting.

2. The resource-supplying activities that will occur anyway should not normally be tabulated as a net requirement.

3. Competing uses for resources can be taken into account by treating the status quo as an alternative.

Data Presentation

1. Quantitative information should be presented to the degree that accuracy is appropriate to the data.

2. Where possible, sources of uncertainty should be specified.

In the United States, the trend toward measurements of energy services has very practical outcomes. Because energy services are provided by a mixture of fuels, labor, and capital, the focus on service allows economic optimizations to be more easily made than in analyses using energy flows. It is on the basis of such a service approach that comprehensive studies of the energy conservation potential of the United States have been done that, unlike most econometric studies, incorporate technical as well as economic characteristics of the major energy-consuming sectors (Yergin 1979; Carhart 1979).

Another practical result of this service focus can be seen in the push to change taxation, regulation, and public consciousness to encourage the creation of markets for energy services in addition to the existing markets for fuels (Sant, 1980). A pioneering, extremely cost-effective, and highly successful effort was undertaken in Oregon in which local and state government modified their regulations so that electric utilities could include home conservation investments in private homes as part of their rate base thereby moving toward the creation of a market for "house comfort" (Malichuk 1980). This practical illustration of the value of the energy service approach has placed additional pressures on the United States Congress to act on proposed measures designed to encourage similar efforts around the country (Federation of American Scientists 1980).

Another advantage of this approach is less immediately practical but important for adapting energy statistical methods to cover all forms of energy. Many uses of direct solar energy and other forms of renewable energy are not well measured in the energy statistics that are gathered in most countries. It is not easy, for example, to determine the amount of energy used by a passive solar home that may be as comfortable as one heated by oil. Putting the emphasis on services is one way of handling this discrepancy (Reister and Devine 1979). Moreover, the services approach is a way of avoiding the energy indexing problems mentioned in the section on fuel linkage. Hydropower, for example, has always been difficult to include in standard statistical tabulations, because it is not clear whether its energy content should be considered to be only that of the electricity it generates (as the United Nations tabulated it) or, equivalent to the fossil energy needed to make the same amount of electricity (as the International Energy Agency tabulates it). If services were the unit of measure, this ambiguity could be prevented. The worry has been that as renewable energy sources like hydropower become more important in national energy decisions, the lack of a proper indexing method will become a major handicap.

The use of services rather than flows as a statistical unit of analysis would not be justifiable if the new tabulations were exactly parallel to the standard ones. Preliminary accounts of energy services in the United States, however, are substantially different from the standard energy flow accounts. Various heat-producing services, for example, are much less prominent according to the services measure (Reister and Devine 1979). Preliminary studies in the United Kingdom also indicate a substantial difference (Leach et al. 1979). Indeed, a study for the Office of Energy

Information of the U.S. Department of Energy recommended that U.S. energy statistics be modified to include service categories so that renewables could be properly taken into account (Devine and Resiter 1979).

In those parts of the world where renewables are an important fraction of energy flows today, there is even greater cause for suspicion that standard statistical methods may be misleading. In the case of small-scale energy technologies operating at village level, an additional justification for using energy services rather than energy flows as a unit of measure is the extent to which SSETs operate at the final consuming sector and are in complicated interaction with human life. This complexity is not well reflected by simple energy flow measures.

Rural Tasks

The energy service approach is still in its formative stages, and much additional conceptual and data work needs to be done before an adequate understanding of energy services and their proper measures can be developed. This is true in the developed economies, where data are more plentiful and the large fraction of energy use in intermediate production sectors makes the problem conceptually easier than in developing economies. Little work seems to have been done to date on energy services appropriate to the rural areas of developing countries, except to the extent that the categorization of development problems by "basic needs" can be translated into energy services. The principal concentration of the FLERT approach at this phase of its development is toward the complexification and distillation of the resource requirements of SSETs and fitting them into local situations. The FLERT approach is designed to mesh with a similar elaboration of rural energy services, but this development requires research and data beyond that presently available. It is nevertheless possible to discuss a general outline of the structure of rural services. The reader should keep in mind that the following observations are conceptually unstructured and largely based on unsystematic and anecdotal data.

As discussed above, it seems useful to divide rural services into the same three categories as resources--physical, social, and environmental. Because of the various other meanings of the terms "environmental services" and "social services," we have chosen to use the word 'tasks" to avoid confusion. What follow are suggestions for organizing rural development problems according to tasks in these categories. The first category, "physical tasks," is the FLERT equivalent of the energy services concept discussed above.

Physical tasks

In an effort to explore the energy service approach, one study developed an inclusive list of energy services for the United States (Devine 1979). The list duplicated in Table 11, consists of 15 categories and suggested measurement units. The units are compromises between complete set

Table 11. Energy Services in the United States

Service	Measure
General energy services	
1. Space heating	Heat into room
2. Water heating	Heat into water
3. Space cooling	Heat from room
4. Refrigeration	Electricity consumed
5. Cooking	Heat into cookware or food
6. Drying	Heat into drying space
7. Lighting	Electricity consumed
8. Electronic services	Electricity consumed
9. Appliance services	Electricity consumed
Industrial process energy services	
10. Process heat	Heat provided by temperature class and transfer medium
11. Mechanical drive	Electricity consumed
12. Electroprocesses	Electricity consumed
Mobile equipment services	
13. Short-range equipment	
a. Mobile machinery	Fuel consumed
b. Service vehicles	Equipment-kilometers
14. Transport	
a. Passenger	Passenger-kilometers
b. Freight	Ton-kilometers
15. Feedstock	Heat equivalent

Source: Modified from (Devine 1979).

of true service measures, such as passenger-kilometers, and surrogates such as electricity consumption in lighting (instead of lumen-hours).

For rural areas of the developing world, the categorization would be somewhat different. Table 12 offers a preliminary listing of such tasks and a set of measures somewhat more task-oriented than those included in Table 11. (Smith et al. 1980). It also breaks certain tasks (cooking, for example) into several categories of subtasks because of their importance as rural basic needs and because of the special attention they receive in rural energy development efforts (stove design, for example). Categories marked with an asterisk are important today in most areas. Expansion of traditional energy sources or provision of new fuels for these services are the most critical and direct purposes of energy programs in rural areas. Two other services, refrigeration and electronic tasks, are often listed as particularly important for increasing welfare at the margin. The rest are of minor importance over wide areas at present, but may be increasingly critical as development proceeds. Space heating, of course, is a task as dependant on climatic factors as on development level.

A study done at the Solar Energy Research Institute identified seven basic needs for energy in the rural areas of developing countries--cooking, drying, and processing of food; provision of potable water: space heating and refrigeration; and irrigation (Ashworth and Neuendorffer 1980). Except for one, they are quite similar to those listed in Table 12. Provision of potable water can of course be classified under pumping, boiling or whatever particular process is utilized. One may usefully think of it as a task in itself, however, because of its extreme importance in many rural areas. On the other hand, because the processes for making potable water are so diverse, it is difficult to establish an energy-related measurement unit. Other observers have also developed similar lists, some in connection with the conference cited at the outset of this report (UNIDO 1979).

Tasks, like resources, can be classified according to their temporal and spatial characteristics as well as by amount. The easiest to determine of these measures is the peak power requirement. This is a necessary temporal parameter for determining a task's fit with various fuel forms and the required energy-production capacity and storage. It is also a surrogate for intensity--a spatial measure--as discussed below. Related to peak power are <u>frequency</u> and <u>variation</u>. These characteristics are analogs for the two temporal measures of fuels listed in Table 2.

Most tasks can be assigned to one of four frequency categories (Figure 13):

1. <u>Hourly or less, or continuous.</u> This group of rural tasks demands an almost uninterrupted supply of energy carrier. Two examples are electricity-powered refrigeration equipment and electricity-powered clocks. Clocks require energy on a continuous basis; refrigerators require energy whenever their thermostats respond to temperatures above a certain setting.

Table 12. Physical Energy Tasks in Rural Developing Areas

Task	Measure
General Energy Tasks	
1. Space heating	Heat into room
2. Water heating	Heat into water (less than 80°C)
3. Space cooling	Heat removal from room
4. Refrigeration	Heat removed from space
*Cooking	
5. Boiling	Kilogram-hour (rice)
6. Roasting	Kilogram-hour (meat)
7. Baking	Kilogram-hour (bread)
8. Frying	Kilogram-hour (vegetables)
9. Drying	Heat into drying space
10. *Lighting	Lumen-hours
11. Electronic services	Electricity consumed
12. Appliance services	Mechanical energy equivalent
Agricultural Services (including crop processing)	
13. *Irrigation	Ton-meters
*Mechanical tasks (including short-distance hauling)	
14. Mobile	Mechanical energy
15. Stationary	Mechanical energy
16. *Crop drying	Heat into drying space
Industrial services	
17. Process heat	Heat equivalent by temperature class
18. *Mechanical drive	Mechanical energy
19. Electro-processes	Electricity consumed

Table 12 (continued)

Task	Measure
Transport	
20. *Passenger	Passenger-kilometers
21. *Freight	Ton-kilometers
Feedstock	
22. *Fertilizer	Heat equivalent
23. Other	Heat equivalent

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*Indicates presently important energy tasks in many rural areas of developing countries.

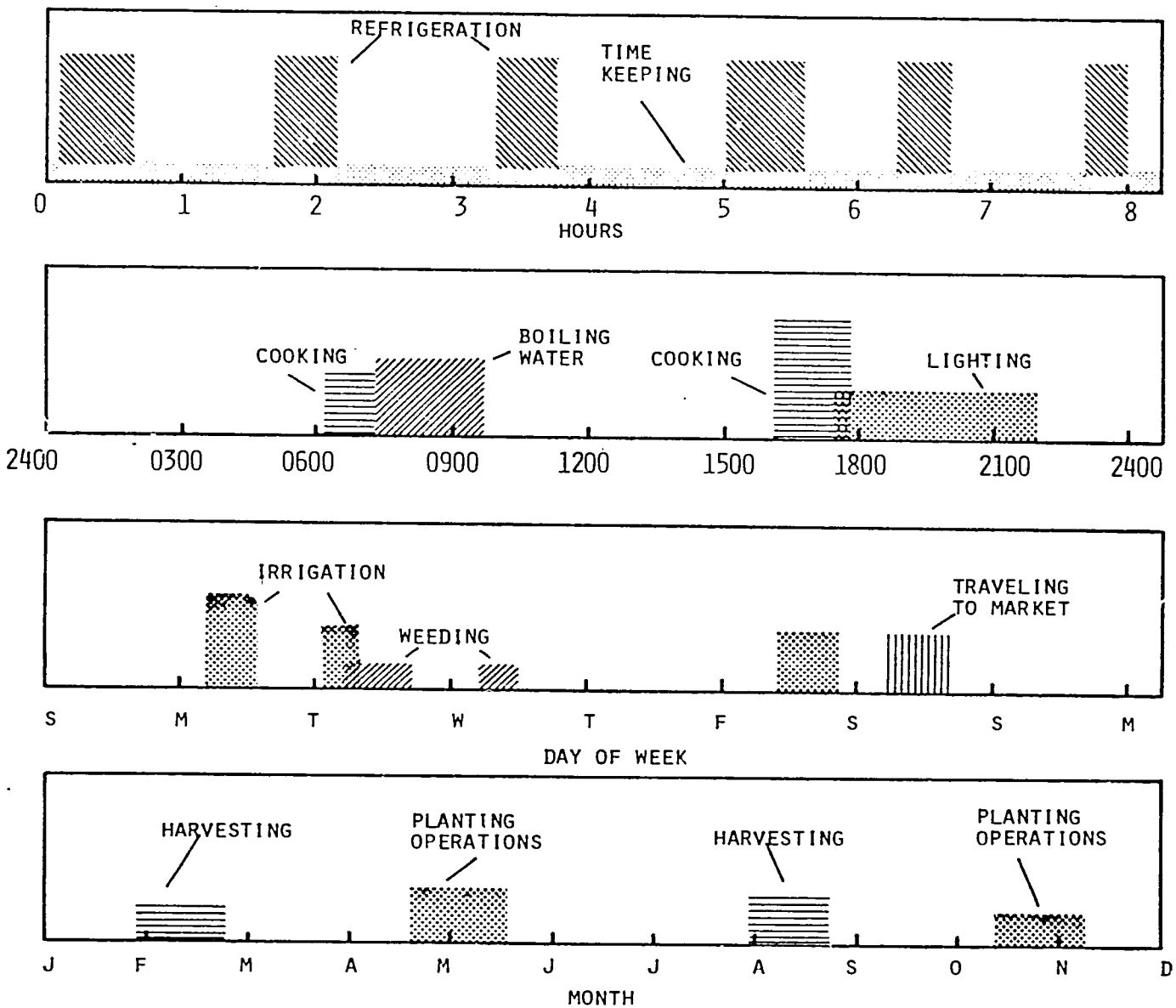

Figure 13. Frequency of tasks. Each type of task is generally performed at characteristic intervals. These can usefully be divided into hourly, daily, weekly and yearly categories.

2. Daily. Tasks in this category are repeated either daily or more than once daily (but not hourly). Cooking meals, an obvious example, is usually repeated once or twice daily in rural areas. Boiling water for drinking purposes, a similar task, may be performed either daily or less often, depending on the storage capacity of a potable-water container.

3. Weekly or monthly. Tasks in this group are performed from once to several times per week or month. Traveling to market or irrigating vegetables during the dry season are examples.

4. Seasonally or annually. These important tasks are frequently associated with agricultural cycles. Planting and harvesting operations are examples of energy-consuming tasks performed one or more times per year.

The second aspect of the temporality of rural tasks is the degree of allowable variation (or flexibility) in the time allotted for performing the task. For hourly or less, or continuous tasks, such as refrigeration or keeping time with an electric clock, requires an almost uninterrupted supply of energy with little or no flexibility about when the energy is available. The time span for performing daily tasks, such as cooking meals, also might not be very flexible because of work schedules or custom. Boiling water for drinking or collecting fuelwood, on the other hand, might have relatively minor daily time constraints. Many agricultural tasks have quite inflexible performance times. As little as a week or two's difference can spell success or failure in planting, fertilizing, irrigating, and harvesting for some areas. Other agricultural tasks, such as weeding, field maintenance, and pruning, may have more flexible schedules.

Fuels must have peak power requirements similar to those of the task, be available on a similar frequency, and be as predictable as appropriate to the allowable variation in the time of task performance. This variation can be measured as the percentage of deviation allowable in each frequency class. Thus, in one village cooking might be a twice-daily task with an allowable variation of + 2 percent (one half hour), whereas boiling water might be a twice-weekly task with an allowable variation of + 15 percent (one day). Table 13 lists these suggested temporal characteristics of tasks and possible measures.

The spatial characteristics of tasks might be specified by energy intensity and siting flexibility (Table 13). These characteristics mesh with the spatial measures used for fuels presented in Table 2. Some tasks--crop drying, for example--can be done at more than one location, whereas others--lighting for example--are quite inflexible in this regard. It is possible to assign subjectively, or perhaps measure directly, a degree of siting flexibility for each task. Energy intensity is the companion not only to the energy production capacity but also to fuel density, for it indicates the potential ease of transporting fuel to the site. A low-density fuel is inconvenient to transport to a high-intensity task unless storage is provided.

Table 13. Temporal and Spatial Characteristics of Rural Energy Tasks

Characteristic	Measure
Temporal	
Frequency (hourly, daily, weekly, yearly)	Number per unit of time (e.g., twice per day)
Allowable variation	Percentage of deviation (e.g., ± 2%)
Spatial	
Siting Flexibility	1, 2, 3[a]
Intensity (peak power)[b]	Energy/time[c]

---

[a]Subjective measure.

[b]Also an important temporal measure.

[c]Energy units as in Table 2.

Social and environmental tasks

In addition to performing physical tasks such as those listed in Table 12, fuel-using technologies cause changes in social and environmental systems. Although it is more difficult to specify and measure those changes, Tables 6-8 listed social and environmental resources that could, in most cases, be considered relevant categories of tasks as well. Biogas systems, for example, perform soil conservation tasks, and community SSETs of various kinds may promote village cooperation or change village social customs. It has been stated that particular fuels (e.g., electricity) tend to promote certain types of social structure (Lovins 1977). More research is needed to establish the extent of this effect, but a task framework is one way in which such effects could be organized and compared.

In spite of the difficulty of specification, it is apparent that social and environmental tasks of considerable importance exist in rural areas and that they are affected by SSETs. Consequently, just as it is appropriate to specify the complexity of physical tasks, it seems appropriate to judge SSETs on the basis of how well these other tasks are performed. In many cases, social and environmental tasks are not the primary intended outcome, but an evaluation of their value can sometimes be crucial for determining the overall appropriateness of small-scale energy technology.

SPECIFICATION PLATES; TOWARD A DISTILLATION

If the process of complexification described in the previous sections were carried to completion, it would generate a tremendous amount of data. Many of these data are not available for most SSETs at present even for such relatively well-studied systems as biogas digesters (Santerre and Smith 1980). Although it will be worthwhile to spend the time, effort, and money to gather data in some of the many FLERT categories, other categories of data will have less priority, and still others will be unnecessary in particular situations.

It may be useful to follow the "specification plate" approach explained in the introduction in order to reduce the number of data to a manageable set. For the specification plate to be useful, the number of categories probably has to be kept to less than a few dozen. What the best categories might be depends on the available data, the special characteristics of the particular class of SSET, the existence of special local conditions, and the concerns of the decision-makers. The interaction of these factors is explored in the case of an actual SSET (anaerobic digesters) in the next report in this series (Santerre and Smith 1980). Despite the need to tailor the specification plates to some extent, it is possible to identify a set of what might be considered basic specifications. There are important for a wide range of SSETs in a variety of locations.

Tables 14-16 offer suggestions for this basic set of resource specifications. Most are not new, but it should be remembered that the FLERT structure from which the numerical values are derived, assures a reasonably

Table 14. Specification Plates: Physical Resources

Resource	Construction (per unit of capacity) Life time = _____		Operation (per unit of energy) Capacity factor = _____		Total (per unit of energy produced)
	Local	National or international	Local	National or international	
Materials					
Fabricated (1)					
Total metals (2)					
Total nonmetals (3)					
Special requirements (4)					
Fuel (5)	a	b	a	b	c
Water[d] (6)					
Capital (7)					

a. For fuelwood equivalents, etc., see Table 2.
b. Kerosene equivalents are a good first order measure.
c. Care must be taken when summing energy contents of different energy forms.
d. Water consumed in construction (e.g., to make concrete) or operation (e.g., added to digesters).

Table 15. Specification Plates: Social Resources

Resource/Measure	Construction		Operation	
	Local	National	Local	National
Unskilled labor (8)	(Per unit of capacity)	(Per unit of capacity)	(Per unit of energy produced)	(Per unit of energy produced)
Skilled labor (9)	(Per unit of capacity)	(Per unit of capacity)	(Per unit of energy produced)	(Per unit of energy produced)
Extensive measures				
New job types (10)				
Village organization (11)				
Sophistication (12)				
Monetary economy (13)				
Land tenure (14)				

Table 16. Specification Plates: Environmental Resources

Resource/Measure	Construction (per unit of capacity)	Operation	
		Amount	Variation
Flowing Water (energy) (15)		Per unit of energy produced	
Other water (e.g., cooling) (16)		Per unit of energy produced	
Exclusive land (17)			
Shared land (18)			
Extensive Measures			
Climate: Wind (19)			
Insolation (20)			
Rainfall (21)			
Temperature (22)			
Soil type (23)			

consistent and reliable presentation--something notably lacking in much of the SSET literature at present. Use of the structure will help to increase the compatibility and accuracy of the data as well as to foster the choice of the most relevant categories.

Listed are 23 specifications, most of which can be applied to any SSET. Some of the environmental resource categories (E.g., wind) are not relevant to all SSETs. If these specifications were available for each SSET, along with information about potential sites, the fit--the appropriatness-could be established.

Physical resources: Table 14

It is valuable to subdivide physical resources further by time--into construction and operational phases--and by space--into those that are locally derived and those "imported" into the village (Table 14). It is important to make a distinction between materials derived from domestic sources and those imported from other countries; therefore, a further subdivision will necessary. Fuels imported into the village could be measured simply by their kerosene equivalent, the conventional fuel of most interest to policy-makers. For locally derived fuels, the proper units are those listed in Table 2. It may also be valuable to consider density and predictability measures, as already discussed, depending on the availability of data. By the definitions adopted in the FLERT approach, only water actually consumed in the process of construction or operation is included under physical resources. Capital is included as a resource even though FLERT is an extraeconomic approach, because capital is an important and limited resource. Obviously, however, it is a different sort of resource from the others in that it is an aggregate measure of other resource requirements. To some extent, including it is a form of double-counting.

Social resources: Table 15

Labor can be divided into many categories, but at minimum it seems useful to distinguish between unskilled and skilled labor requirements (including technical and professional). The rest of the social resources listed here are best indicated by extensive measures. Utilization of extensive measures assumes that one unit of a technology (e.g., a windmill) would require the same amount of these resources as would twenty--i.e. that they are not used in proportion to increased capacity or energy production. What is listed in Table 15, therefore, is the minimum qualitative level of each resource necessary for success. The resources listed seem to be both relatively important and relatively amenable to measurement, but much additional work is needed to confirm these impressions. In the case of social resources it is also important to distinguish between the requirements at local and national levels. Different SSETs have quite different demands in this regard. Photovoltaics require a high degree of sophistication at the national level for manufacture but may demand minimal sophistication in installation and use. In contrast, complicated biogas-aquaculture-fertilizer-lime operation with heated

digesters and several integrated chemical or biological systems would require a great deal of sophistication at the local level.

Environmental resources: Table 16

Table 16 lists two types of water requirements under the category of environmental resources. If flowing water is tapped as an energy source, there must be not only a sufficient amount per unit of capacity but also a certain amount per unit of energy produced. Water may be needed for cooling for filling ponds, or for other nonconsumptive uses. Of course, some water will be lost through evaporation and leakage by these processes, and the amount should be tabulated when water is a particular constraint. The quality of water required might also be important in some circumstances. Land cannot be used up in most cases and therefore might be listed as an extensive resource. Land area does vary with installed capacity, however, and for that reason is considered here to be an intensive resource. It is useful to make the distinction between land exclusively occupied by the SSET (under a digester, for example) and land shared with other uses (such as a photovoltaic array on a building roof or crop lands producing both grain and agricultural residues). It is important to know both the level of each climatic resource required (e.g., annual temperature) and the allowable variation. For these resources and water, therefore, it might be valuable to include measures of amount and variation in the specification place.

General considerations in specification plates

The suggested specification plates in Tables 14-16 disaggregate many of the resource requirements: (a) resources that are available from within the village, in the form in which they are used (the column marked "local"), and (b) resources that are transported into the village, in the form they are in when they cross the village "boundary" (the column marked "national"). The spatial limit of the analysis is the area bounded by the village. We are defining a village as a rural settlement within some convenient geographic, political, or jurisdictional boundaries, that includes clustered or outlying dwellings, as well as agricultural or nonagricultural lands and businesses owned, used, or controlled by the residents.

Thus, the analysis does not account for resources that are used to produce the second category of resources described above. Although it does account for the amount of steel plate brought into the village for building a steel floating gas collector for an anaerobic digester, for example, no attempt is made to account for the resources used to mine the iron ore, build the foundry, or fabricate the steel plate. If a national input-output data base were available, these other resource requirements could then be elaborated.

If, for example, an electrical generator were brought into the village as a component of a windmill, it would be tabulated as an electrical generator, rather than the amount of steel, copper, paint, plastic, or other materials

from which it was built because an electrical generator was the form these materials were in when they crossed the village boundary.

For resources that are available within a village, such as sand and water, additional resources will be invested for their procurement--i.e., it requires labor to collect and transport sand and water to the site of the energy production system. These will be tabulated, for they may be important resource inputs at the local level. (See Figure 11.)

The temporal boundaries of the analysis, in contrast to the spatial, extend backward in time to production activities that occurred well before the construction of the energy technology in question. This simple specification plate begins with the procurement of local resources and actual construction of the energy technology. It does not include the research, development, and demonstration of the technology done before the energy device was built.

For the purpose of establishing temporal boundaries, it is necessary to assume that energy systems have finite life expectancies. Although certain energy systems have a definite useful service life (e.g., windmills), others, such as biomass energy farming, do not. The latter can produce energy indefinitely, if properly managed, and therefore some artificial planning horizon--e.g., 30 years--must be applied to them.

Other aspects of resources can also be important. Table 16 notes the distinction between shared and exclusive use in the case of land. Tools are another resource having a shared character. They may be essential to the construction, operation, and maintenance of an energy production system: but they are "shareable" in the sense of their possibly being available for uses besides those to which they are put in construction, operation, and maintenance of the energy production system.

As discussed above, the water used to make concrete was not simply appropriated temporarily, but became unavailable for other purposes. On the other hand, the water used to dilute the organic raw materials used as feedstock for anaerobic digestion could be considered a shared resource. This water could have been used as wash water before being put to use as a dilutent, and after its removal from the digester could be used for irrigating crops. In contrast, water used for irrigating a biomass energy crop would not be considered a shared resource; it is appropriated (by seepage into the soil, incorporation into plant tissue, or evaporation) by the energy system, at least in the short run, and hence would be considered an exclusively used resource.

The distinction between shared and exclusive resources is different from that between extensive and intensive ones. Shared resources can be used up, unlike an extensive resource such as temperature, but the amount used to build or run a particular SSET is difficult to determine. It is not worthwhile, for example, to calculate what fraction of a wrench is consumed in the construction of a windmill.

Another criterion which has been applied only to land in Table 15 but

could be applied to other resources, is ownership and control. The availability of resources required by energy production systems is often as dependent on the ownership and control of the resource as it is on the physical availability of the resource in the village. For example, in villages of India where animal dung is dried and used as cooking fuel among poorer households, the introduction of anaerobic digesters could reduce the access of poorer households to the dung. Such a scenario became reality in places where anaerobic digesters were acquired by and became popular among wealthier households.

Three categories of ownership and control might be considered. The first pertains to most privately owned resources available in rural areas, such as land (together with mineral, siting, and right-of-way rights), animals, crops, and crop residues. The second applies to government resources; such things as inland bodies of water and roadways. The third category applies to a number of apparently uncontrolled and unowned resources, such as wind and solar energy, which ar in practice controlled by individuals, firms, and governments having access rights. For example, access to sunlight that falls on the surface of the earth is controlled by the owners or controllers of land. Access to the "free" wind energy resource is similarly controlled by those who own the land on which windmills must be sited. If ownership and control of nonland resources are considered potentially critical, this additional criterion can be added to the specification plates.

Finally, as discussed above, it is important to remember that the specification plates directly reflect gross requirements. They tabulate all the land, labor, materials, and fuels needed by the SSET. Gross requirements must not be confused with the net change in resource flows that would occur if an SSET were put into place. In the case where the SSET is designed to replace an existing method of achieving a particular task, net requirements are determined by subtracting from the gross requirements the resource flows now used to achieve the same task. In many situations, however, the net requirement is more difficult to determine because the potentially displaced resources are being used in ways quite different from their use in the proposed SSET. What, for example, is the net labor requirement of collecting dung for a digester when it already is being collected for fuel, fertilizer, and plaster? The answer depends on the particular situation and can only be determined by considering both the net resource requirement (for example, additional hours of labor to handle dung beyond what was applied before) and net tasks performed or products provided (for example, more cooking fuel, more fertilizer value, but less plaster). In Santerre and Smith (1980), the complexities of net and gross requirements of anaerobic digestion are discussed further.

CONCLUSION

The FLERT approach addresses the first four guidelines for appropriateness indicators listed in Table 1. The sample distillation into specification plates shown in the preceding section shows what information might be chosen to meet the last guideline in Table 1, the criterion of

parsimony. As a summary, Table 17 presents all of the measurements and other data that go into this sample set of specification plates. The FLERT approach meets these guidelines through a highly structured and relatively quantitative framework that is so complex in parts that it borders on the baroque. The appropriate tradeoffs--i.e., relative weights--among the different appropriateness indicators (resource fit versus task fit, for example) will have to be decided by the user. Like the specification plate on a stereo set, these specification plates do not produce decisions; they only facilitate them. They are capable, however, of generating conceptually consistent data sets.

The FLERT approach can be applied to various policy problems. It can help match energy technologies to village resources and needs, for example. This is a major aspect of appropriateness. In addition, it can help distinguish between requirements at the village level and those needed nationally or internationally. Thus, not only does it enable village-level implications of a commitment to different SSETS to be established. This sort of comparison requires a relatively large data base, but is of interest to many national planners.

Most obviously, it is possible to compare different SSETs using the FLERT approach. The information found in the specification plates can be used to illustrate the implications of different options. For example, the alternative uses of a particular resource can be determined; this is shown in Figure 4 of Santerre and Smith (1980). Alternatively, differences in resources required by different SSETs can be compared to perform the same task.

The approach offers other possibilities as well. For example, the resource effects of different scales of the same technology can be explored. This has been attempted in Santerre and Smith (1980) for some aspects of anaerobic digesters. The FLERT approach thus provides a means to examine by type and scale of installation the appropriateness, or fit, of resource-altering technologies to local tasks.

Combining the FLERT measure of resource and task fits with the practical experiences of success and failure in SSET introduction could lead to an increased understanding of the viability threshold discussed in the introduction. Presumably, those SSETs with greater task and resource fits will be more likely to cross the threshold to become a viable part of rural life.

Although applicable mainly to macrolevel policy-making, such as regional and national programs of technology implementation, the FLERT approach could be used to develop techniques for increasing the chances for success of individual installations. Volunteers in Technical Assistance, or VITA, (1980) have developed a questionnaire designed to help people decide on the best type of SSET for their particular situation. It queries prospective SSET users (whether individuals or communities) about their local resources and energy needs. The FLERT structure not only would suggest additional categories of questions, but also might help to frame the questions so that a consistent tabulation of the responses could follows.

Table 17. General Specification Plate Concerning Most SSETs

Specification	Number of Total Possible Data Points	Tables
Resource Fit		
Physical resource requirements 7 categories	33	2,5,14
Social resource requirements 7 categories	28	6,7,15
Environmental resource requirements 9 categories	15	8,16
Resources listed per unit of energy produced or capacity installed		2
Resources determined via a set of accounting rules		10
Task Fit		
Fuel form	1	2
Fuel replacement matrix	a	4
Spatial and temporal measures of fuel	4	3

Note: (Not all resource categories are revelant to all SSETs.)

Classification scheme results in 60-70 data points for each SSET's Specification Plate.

a. The fuel replacement matrix is common to all SSETs.

The process for matching renewable energy systems to village energy needs developed at the Solar Energy Research Institute (Ashworth and Neuendorffer 1980) deals with many of the same issues considered in the FLERT approach. It also directs itself to energy needs in the context of temporal, spatial, environmental, and social concerns. The FLERT approach is complimentary in its elaboration of resource requirements, focus on quantification and consistency, and coverage of tasks beyond meeting basic energy needs. In addition, the FLERT approach attempts to draw directly from the growing disciplines of resource analysis and energy service accounting which have developed recently within the energy research community.

Other structured approaches exist that have been or could be applied to judging the viability of SSETs. These include techniques adapted from benefit-cost analysis (Bhatia 1980), risk analysis (Roumasset 1977), engineering process models (Servian 1975), and sociology (Koppel and Schlegel 1979). It is also possible to adapt linear programming and optimization techniques to mathematical models of village resources and needs (Chulalongkorn University 1980). It appears that each of these techniques will have appropriate applications, although their relative efficiencies and validities in different settings will vary. Finding, defining, implementing, and sustaining small-scale technologies appropriate to material and social development will require these tools and many others.

REFERENCES

Ashworth, John H., and Jean W. Neuendorffer. 1980. Matching Renewable Energy Systems to Village-Level Energy Needs. SERI/TR-744-514. Golden, Colorado: Solar Energy Research Institute.

Bhatia, Ramesh. 1980. An Analytical Framework for Socio-economic Assessment of Technological and Policy Alternatives. Resource Systems Institute Conference Paper. Honolulu: East-West Center.

Boyd, David A. 1980. The Stochastic Sun: Understanding the Intermittent Resource. ORAU/IEA-80-10(M). Oak Ridge, Tennessee: Institute for Energy Analysis.

Brown, Harrison, and Kirk R. Smith. 1980. Energy for the People of Asia and the Pacific. Annual Review of Energy 5:173-240.

Caputo, Richard. 1977. An Initial Comparative Assessment of Orbital and Terrestrial Power Systems. Jet Propulsion Laboratory Report 900-780. Pasadena, California: California Institute of Technology.

Carhart, Steven. 1979. The Least-Cost Energy Strategy: Technical Appendix. Arlington, Virginia: Energy Productivty Center Medon Institute.

Carpenter, Stanley R. 1974. Modes of Knowing and Technological Action. Philosophy Today 28(214):162-168.

Carusso, M., J. Gallagher, K. Sharma, J. Gagle, and R. Barany. 1975. Energy Supply Planning Model. Bechtel Corporation Report 10900-900 75-31. 2 vols. San Francisco: Bechtel Corporation. (update 1978).

Chatterjee, Manas K. 1979. Remarks on Energy Commodity Balances with Special Reference to Solid Fuels. In Proceedings of Workshop on Energy Data of Developing Countries, Vol. 1, Summary of Discussions, Technical Paper:74-76. Paris: Organization for Economic Cooperation and Development.

Chulalongkorn University. 1980. Development, Introduction and Commercialization of Solar Water Heaters, Cookers and Dryers. A research proposal by the Engineering Institute of Research and Development Bangkok, Energy for Rural Development Steering Committee Meeting. Honolulu: East-West Center.

Craig, Paul, M. Christensen, M. Simmons, M. Levine, and M. Mukamel. 1978. Distributed Energy Technologies in California's Energy Future. Interim Report HCP/P7405. 2 vols. Berkeley, California: Lawrence Berkeley Laboratory.

Devine, Warren D. 1979. Energy Accounting for Solar and Alternative Energy Sources. ORAU/IEA-79-11(R). Oak Ridge, Tennessee: Institute for Energy Analysis.

Devine, Warren D., and David B. Reister. 1979b. Taxonomy and Energy Utilization. Oak Ridge, Tennessee: Institute for Energy Analysis.

Ehrlich, Paul R., Anne H. Ehrlich, and John P. Holdren. 1977. Ecoscience: Population Resources and Environment. San Francisco: W. H. Freeman.

Erhlich, Paul R., Anne H. Erhlich, John P. Holdren, and Kirk R. Smith. Introduction to Ecoscience. (Forthcoming) San Francisco: W.H. Freeman.

Federation of American Scientists. 1980. Energy Conservation and Renewable Energies: A Summary of Legislative Progress. Washington, D.C.: Federation of American Scientists.

Government of India. 1965. Report of the Energy Survey of India Committee. New Delhi:

Grenon, Michel, ed. 1979. Systems Aspects of Energy and Minerals Resources. Procedures of an IIASA/RSI Conference. Laxenburg, Austria: International Institute of Applied Systems Analysis.

Grenon, Michel, and Bruno Lapillonne. 1976. The WELMM Approach to Energy Strategies and Options. RR-76-19. Laxenburg, Austria: International Institute of Applied Systems Analysis.

Hafele, Wolfe. 1980. Energy in a Finite World: A Global Systems Analysis. Laxenburg, Austria: International Institute of Applied Systems Analysis.

Harahap, Filino, B. Kartasasmita, and T. Muljadi. 1979. Appropriate Technology in the District of Sukabumi: A Case Study. Indonesian National Seminar on Rural Technology. Badung: Institute of Technology.

Heilbroner, Robert C. 1959. The Future as History. New York: Harper and Row.

Hittman Associates. 1974. Environmental Impacts, Efficiency and Cost of Energy Supply and End Use. HIT593. 2 vols. Columbia, Maryland.

Holdren, John P., Kent Anderson, Peter H. Gleick, Irving Mintzer, Gregory Morris, and Kirk R. Smith. 1979. Risk of Renewable Energy Sources: A Critique of the Inhaber Report. ERG 79-3, Energy and Resource Group. Berkeley: University of California.

Holdren, John P., Gregory Morris, and Irving Mintzer. 1980. Environmental Aspects of Renewable Energy Sources. Annual Review of Energy. 5:

Illo Jeanne, I. F., and Ricardo G. Abad. 1980. Typological Studies of Village Social Structure in the Philippines. A Research Proposal by the Institute of Philippine Culture, Energy for Rural Development Steering Committee Meeting. Honolulu: East-West Center.

Klitz, J. K. 1979. North Sea Oil: Resource Requirements for UK Development London: Pergamon Press.

Koppel, Bruce, and Charles Schlegel. 1979. Sociological Perspectives on Energy and Rural Development. Annual Meeting. Burlington, Vermont: Rural Sociological Society.

Leach, Gerald, Chris Lewis, Ariane van Buren, Frederic Romig, and Gerald Foley. 1979. Low Energy Strategy for the United Kingdom. London: International Institute for Environment and Development.

Lenk, Hans, and Gunter Ropohl. 1979. Toward an Interdisciplinary and Pragmatic Philosophy of Technology: Technology as a Focus for Interdisciplinary Systems Research. Research in Philosophy and Technology 2:15-52.

Lovins, Amory. 1977. Soft Energy Paths. New York: Harper Colophon Books.

Malichuk, John. 1980. Letter to Oregon Public Utility Commissioner John Lobdell. August 7. Portland, Oregon: Pacific Power and Light.

Merril, Richard, and Thomas Gage, eds. 1978. Energy Primer: Solar, Water, Wind and Biofuels. New York: Dell Publishing.

Mishan, E. J. 1975. Cost-Benefit Analysis. London: George Allen and Unwin.

Mitcham, Carl. 1978. Types of Technology. Research in Philosophy and Technology 1:229-312.

MITRE/METREK Division. 1977. Preliminary Environmental Analysis of Energy Technologies Using the Assumptions of the National Energy Plan, Vol IV: Simulation Data Base. McLean, Virginia.

Moskowitz, P. D., W.A. Sevian, S.C. Morris, and A. Crowther. 1980. A Comparison of Some Energy Supply Sector Emission Coefficients. Upton, New York: Brookhaven National Laboratory.

Nasar-O'Brien, Sylvia. 1979. The Production and Consumption of Non-Fuel Minerals to the Year 2000: Implementing a Global Input-Output Model and Data Base. IIASA/RSI Conference on Systems Aspects of Energy and Minerals Resources. Laxenburg, Austria: International Institute of Applied Systems Analysis.

Odendhal, Steward. 1972. Energetics of Indian Cattle in Their Environment. Human Ecology 1(1):3-22.

Perry, A. M., W. D. Devine, and D.b. Reister. 1977. The Energy Cost of Energy--Guidelines for Net Energy Analysis. ORAU/IEA(R)-77-14. Oak Ridge, Tennessee: Institute for Energy Analysis.

Reddy, Amulya K. N., and K. K. Prasad. 1977. Technological Alternatives and the Indian Energy Crisis. Economic and Political Weekly 12(33-34):1465-1502.

Reister, David B., and Warren D. Devine. 1979. Total Costs of Energy Services. ORAU/IEA-79-12(R). Oak Ridge, Tennessee: Institute for Energy Analysis.

Roumasset, James A. 1977. Risk and Uncertainty in Agricultural Development. Agricultural Development Council Seminar Report, No. 15.

Sampson, Anthony. 1975. The Seven Sisters: The Great Oil Companies and the World They Shaped. New York: Viking Press.

Sant, Roger. 1979. Least-Cost Energy Strategy. Arlington, Virginia.: Energy Productivity Center, Mellon Institute.

Sant, Roger. 1980. Coming Market for Energy Services. Harvard Business Review 58(3):6-24.

Santerre, Michael T., and Kirk R. Smith. 1980. Application of the Fuel-Linked Energy Resources and Tasks (FLERT) Approach to Rural Household and Community Anaerobic Digestion Systems. Resource Systems Institute Program Report 5. Honolulu: East-West Center.

Schlegel, Charles, and James Tarrant. 1980. Thinking about Energy and Rural Development: Methodological Guidelines for Socioeconomic Assessment. Resource Systems Institute Program Report 3. Honolulu: East-West Center.

Schumaker, E. F. 1973. Small is Beautiful, Economics As If People Mattered. New York: Harper and Row.

Schurr, Sam H., Joel Darmstadter, Harry Perry, William Ramsay, and Melton Russel. 1979. Energy in America's Future: The Choices Before Us. Baltimore: Johns Hopkins Press for Resources for the Future.

Science and Public Policy Program, University of Oklahoma. 1975. Energy Alternatives: A Comparative Analysis. Washington, D.C: U.S. Government Printing Office.

Servian, W. A. 1975. The Energy System Network Simulator: General Description and Sample Analysis. Draft Report 50492. Upton, New York: Brookhaven National Laboratory.

Smith, Kirk R. 1979. Problems of Secondary Accounting: The Poor Example of Risk Analysis. Proceedings of the IIASA/RSI Conference on the Systems Aspects of Energy and Mineral Resources. Laxenburg, Austria: International Institute of Applied Systems Analysis.

Smith, Kirk R. 1980a. Interaction of Time and Technology. New York: Garland Press. (Forthcoming).

Smith, Kirk R. 1980b. Environmental Impacts of Renewable Energy Sources: Methodological Issues. In Riazudden, ed., Physics and Contemporary Needs. London: Plenum.

Smith, Kirk R. 1980c. Risk Analysis: Toward a Standard Method. In Proceedings of the American/European Nuclear Societies' Meeting on Thermal Reactor Safety. Springfield, Virginia: National Technical Information Service.

Smith, Kirk R., Michael T. Santerre, and Charles S. Schlegel. 1980. Criterion Framework and Indicators for Comparing and Evaluating Alternative Energy Technologies. Resource Systems Institute Conference Paper. Honolulu: East-West Center.

Smith, Kirk R., John P. Weyant, and John P. Holdren. 1975. Evaluation of Conventional Power Systems. ERG 75-5, Energy and Resources Group. Berkeley: University of California, and 1976. Pasadena, Calif: Jet Propulsion Lab.

Study of Critical Environmental Problems (SCEP). 1970. Man's Impact on the Global Environment. Cambridge, Massachussetts: MIT Press.

Suriyakumoran, C. 1979. Economics of Environmental Planning. Guest lecture at Environment and Policy Institute, East-West Center, Honolulu.

United Nations Environment Programme (UNEP). 1980. African Solar Energy Workshop Summary Report. Nairobi: UNEP.

United Nations Industrial Development Organization (UNIDO). 1978a. International Forum on Appropriate Technology, Ministerial Level Meeting in Anand, India. Vienna: UNIDO.

United Nations Industrial Development Organization (UNIDO). 1978b. International Forum on Appropriate Technology, Report of the Technical/Official Meeting to the Ministerial Level Meeting, Anand, India. Vienna: UNIDO.

United Nations Industrial Development Organization (UNIDO). 1979. Appropriate Industrial Technology for Energy for Rural Requirements. Monographs on Appropriate Industrial Technology, Number 5. Vienna: UNIDO.

U.S. Department of Energy. (USDOE). 1979. Environmental Data for Energy Technology Policy Analysis. HCP/EV-6119/1. Washington, D.C.: U.S. Government Printing Office.

van Buren, Adriane, ed. 1979. A Chinese Biogas Manual. London: Intermediate Technology Publications.

Volunteers in Technical Assistance (VITA). 1980. Energy Fact Sheet. Numbers 1 and 2.

Webster's New Collegiate Dictionary. 1977. Springfield, Massachusetts: G. G. Merriam Co.

Yergin, Daniel. 1979. Conservation, the Key Energy Resource. In Robert Stobaugh and Daniel Yergin, eds., Energy Future. Report of the Energy Project at the Harvard Business School. New York: Random House.

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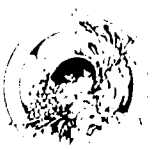

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Raw Materials Systems is concerned with the identification and evaluation of policy and strategy options that will benefit nations from the exploration and development of their mineral resource potential. The main research areas are: mineral assessment for national planning, innovative government-transnational company arrangements, uncertainties in future commodity trade, and case histories of mineral projects.

THE EAST-WEST CENTER—officially known as the Center for Cultural and Technical Interchange Between East and West—is a national educational institution established in Hawaii by the U.S. Congress in 1960 to promote better relations and understanding between the United States and the nations of Asia and the Pacific through cooperative study, training, and research. The Center is administered by a public, nonprofit corporation whose international Board of Governors consists of distinguished scholars, business leaders, and public servants.

Each year more than 1,500 men and women from many nations and cultures participate in Center programs that seek cooperative solutions to problems of mutual consequence to East and West. Working with the Center's multidisciplinary and multicultural staff, participants include visiting scholars and researchers; leaders and professionals from the academic, government, and business communities; and graduate degree students, most of whom are enrolled at the University of Hawaii. For each Center participant from the United States, two participants are sought from the Asian and Pacific area.

Center programs are conducted by institutes addressing problems of communication, culture learning, environment and policy, population, and resource systems. A limited number of "open" grants are available to degree scholars and research fellows whose academic interests are not encompassed by institute programs.

The U.S. Congress provides basic funding for Center programs and a variety of awards to participants. Because of the cooperative nature of Center programs, financial support and cost-sharing are also provided by Asian and Pacific governments, regional agencies, private enterprise, and foundations. The Center is on land adjacent to and provided by the University of Hawaii.

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