Table 3-1 summarizes the regional differences that produce minimum and maximum costs.* As indicated, a coal conversion plant near a coal mine is usally the least-cost option, primarily because coal transportation cost usually exceeds the cost of transporting the final product either from the refinery or from the coal conversion plant. In addition, regional variations in distribution costs are less than variations in coal transportation costs.

F. Sensitivity to the Variations in Cost Parameters

As noted earlier, the sensitivity analysis considers the impact on total cost of the changes in cost of the following factors: coal extraction, coal transportation, coal conversion, refining, product transportation, and product distribution. The details of this analysis can be found in Appendix C.

The results of sensitivity analysis are summarized in Figure 3-6. Note that the greatest improvement in the estimates of delivered fuel costs can be gained by better costs estimates for coal conversion, product liquefaction, and product distribution. Changes in coal extraction and transportation cost produce only modest changes in the total cost when compared with the cost of coal conversion, product liquefaction and product distribution. The total cost shows little sensitivity to changes in cost of transporting the product. The sensitivity to changes in the refining cost of syncrude is also significant.

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*The information in this table must be cautiously used. For example, it is unwise to generalize that minemouth is the best option. First, limitation in networks carrying the fuel from the coal conversion plant to a refinery or to markets of final demand must be analyzed. The analysis must also consider the location of existing refining centers.

Table 3-1
COST SENSITIVITY TO REGIONAL DIFFERENCES

	Cost ($/10⁶ Btu)	Percentage Difference	Coal Conversion Plant Location	Coal Type	Refinery Location (PAD Districts as modified by FEA)	Market/Final Demand Location (Census Region)
1. **Syncrude/ Gasoline**						
maximum	6.30	24%	Beaumont, TX	Appalachian Underground	PAD 2A, 2B, or 3	New England/Middle Atlantic
minimum	5.10		Billings, MT	Montana Surface	PAD-4	Mountain/West North Central
2. **Methane**						
maximum	10.50	14%	New Orleans, LA	Illinois surface	NA	New England/Middle Atlantic
minimum	9.20		Gillette, WY	Wyoming surface	NA	Mountain
3. **Methanol**						
maximum	9.80	10%	Galveston, TX	Appalachian Surface	NA	New England/Middle Atlantic
minimum	8.90		Billings, MO	Montana Surface	NA	Mountain/West North Central
4. **Fischer-Tropsch Gasoline**						
maximum	11.10	9%	Galveston, TX	Appalachian Surface	NA	New England/Middle Atlantic
minimum	10.20		Billings, MT	Montana Surface	NA	Mountain/West North Central
5. **Hydrogen**						
maximum	13.00	16%	Galveston, TX	Appalachian Surface	NA	New England/Middle Atlantic
minimum	11.20		Chicago, IL	Illinois Surface	NA	East North Central
6. **Electricity**						
maximum	14.70	43%	Boston, MA	Appalachian Surface	NA	New England/Middle Atlantic
minimum	10.30		Charleston, SC	Appalachian Surface	NA	South Atlantic

	SYNCRUDE/ GASOLINE	FISCHER-TROPSCH GASOLINE	METHANOL	METHANE	HYDROGEN	ELECTRICITY
COAL EXTRACTION	△	△	△	△	○	○
COAL TRANSPORTATION	△	△	△	△	○	○
COAL CONVERSION	□	□	□	□	□	□
CRUDE TRANSPORTATION	○	NA	NA	NA	NA	NA
REFINING	□	NA	NA	NA	NA	NA
PRODUCT TRANSPORTATION	○	○	○	△	○	NA
PRODUCT LIQUEFACTION	NA	NA	NA	□	□	NA
PRODUCT DISTRIBUTION	□	△	□	□	□	NA
ELECTRIC TRANSMISSION AND DISTRIBUTION	NA	NA	NA	NA	NA	□

○ LEAST SENSITIVE
△ MODERATELY SENSITIVE
□ MOST SENSITIVE
NA NOT APPLICABLE

FIGURE 3-6. SUMMARY OF SENSITIVITY ANALYSES

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Chapter 4

ENERGY ANALYSIS

A. Methodology

Since the concept of net energy began to receive widespread attention several years ago, articles and reports have explored applications of the concept and have made numerical calculations for a variety of energy systems. In addition, workshops have been held to clarify the meaning of energy analysis and to produce a definitive methodology.

In spite of this activity, those involved in energy analysis still do not agree about its definition or its usefulness. In the area of methodology, however, it is generally recognized that several legitimate approaches exist, each of which has its advantages as well as its drawbacks. Three of the most useful approaches are discussed below.

1. Process Analysis

This is undoubtedly the most intellectually straightforward of all the approaches applied to energy analysis.[1] It was devised to determine the total energy consumed in producing such products as automobiles and containers, but it can be applied to fuel production just as readily. It thermodynamically analyzes each process in the chain of activities that are required to produce and deliver a given amount of product (e.g., 1 ton of aluminum). This procedure can be characterized as a vertical analysis because it follows the flow of materials from the basic resources through the processing steps required to deliver a product, explicitly evaluating the energy consumption at each stage. When materials other than those in the main process stream are consumed or added to the process, the energy consumed in producing these materials is evaluated as another source of energy use.

Ultimately, the direct energy consumption associated with each stage of manufacturing is added to indirect energy consumption to yield the total energy required to deliver a unit of the product. Typically, the total energy requirement of the manufacturing and distribution processes is broken down diagrammatically so that the major areas of energy consumption may be clearly discerned.

If the goal of the calculation is a net energy analysis of an energy conversion technology, the procedure differs only in that the unit quantity of the end product (typically a fuel or electricity) is expressed in appropriate energy units, such as Btu.

The process analysis approach is attractive because it clearly displays the energy contribution of each step in the sequence of steps that leads to the production of the final product. The detailed data sources that support the calculation of energy consumption in each step can be given in footnotes, allowing the reader to verify the numerical values in the analysis independently. Furthermore, technological advances or alternative processes that change the efficiency or energy consumption of any step can be easily incorporated in the analysis.

The major disadvantage of process analysis is that the calculation of second- or third-order contributions to energy consumption (e.g., the energy consumed in producing mining equipment used in mining iron ore that is used to produce steel for power plants) becomes tedious. And considerable branching quickly occurs one or two levels away from the main process sequence. Thus, a simple rule of thumb is that second- or higher-order contributions should be abandoned once numerical contributions become the same order as the range of error in the calculations for the main process sequence. Nevertheless, substantial effort can be expended in discovering which higher-order contributions are significant and which are not. The technique that follows provides an alternative, concise mathematical means of accounting for such higher-order effects.

2. Input-Output Analysis

The use of input-output analysis to describe the flows of goods and services in the U.S. economy has been a powerful tool of economic theory since it was introduced in the 1930s. It has been only recently, however, that this approach has been extended to include flows of energy, primarily by Robert Herendeen and Clark Bullard of the University of Illinois.[2]

To formulate an input-output description of the economy, all business activities contributing to the nation's GNP are grouped into sectors; each sector represents activities of a particular type (e.g., coal mining, canned sea foods, cigarettes, and textile goods). Currently, the largest number of sectors used is 368. The transactions measured in dollars' worth of sales per year between each sector and all other sectors are tabulated and displayed as a matrix of 368 rows and 368 columns. In addition, the sales of each sector to final demand (personal consumption, government purchases, purchases of capital goods, and the like) are tabulated.

The extension of this economic input-output formulation to energy input-output requires additional data on the direct consumption of energy by each of the 368 economic sectors. In other words, each sector's actual purchases of coal, petroleum products, natural gas, and electricity must be determined. (Crude oil and gas are purchased only by the refined petroleum products and gas utilities sectors.) Once these data have been incorporated with the dollar flow input-output structure of the economy, a computer can calculate the total direct and indirect energy consumption embodied in a dollar's worth of goods or services purchased from any sector. If, for example, an automobile is purchased from the motor vehicles and parts sector for $4,000, the total energy consumed in the production of that automobile can be determined. This total energy consumption includes both the energy consumed directly by the motor vehicles and parts sector as well as the energy consumed by all the sectors that supplied it, all the sectors that supplied these sectors, and so on. In other words, the flows of energy in the production of any goods or service and traced back automatically through all other sectors of the economy to determine the total consumption of resource energy required to deliver the goods or service. For five energy sectors--coal mining; crude oil and gas production; petroleum refining; gas utilities; and electric utilities--the energy requirements are expressed in energy consumed per Btu of output. This constitutes, in effect, a net energy calculation for each of these sectors.

A net energy analysis of new energy technologies, such as oil shale or solar energy using the input-output method depends on the ability to disaggregate the capital and operating costs associated with the technology into specific economic sectors. Purchases from these sectors are then converted into energy flows as outlined above, and the total energy required to produce a given amount of a product can be calculated. This calculation assumes a small contribution from the new technology to the overall energy budget of the United States. Thus, feedback loops--the flow of energy from the output of the technology through other sectors and back to that technology as indirect energy consumption--can be ignored. These feedback effects, however, cannot be ignored in a mature industry such as petroleum refining.

The main disadvantage of input-output analysis is that even at the level of disaggregation of 368 sectors, each sector may contain a wide variety of activities. The energy required to produce a dollar's worth of output in one industry may be quite different from that required in another industry, even though both industries are classified in the same sector. As a result this analysis may lead to significant errors in some calculations. Nevertheless, input-output analysis remains a powerful technique for tracing flows of energy through the U.S. economy.

3. Odum's Approach

A key feature of the school of thought evolved by Howard Odum and his students, and now receiving widespread attention, resides in the explicit consideration of natural energy flows as they affect man.[3] Odum was among the first to point out that many of man's activities are "subsidized" by nature in the form of "free" services that are lost when natural ecosystems are disrupted. Often, these lost services can be replaced only through man-made technologies that require large subsidies of materials and fossil energy. Thus, the energy subsidies in natural systems that may be disrupted or destroyed by implementation of an energy technology must be explicitly evaluated as an energy cost.

Oil shale will serve as an illustration in the hypothetical case that follows. Oil shale retorting and upgrading would require large amounts of water from the upper Colorado River. This water is relatively pure. If unused, it dilutes the water of the lower Colorado, which is contaminated with dissolved salts. Removal of upper Colorado water thus increases the salinity of the lower Colorado, which is used to irrigate crop lands. If this water becomes too saline for irrigation, desalination plants have to be built. Construction and operation of these plants require materials and energy. Thus, a natural subsidy will have been destroyed, and the energy equivalent of the service might logically be charged against the energy output of the oil shale industry, as well as against other energy industries using upper Colorado water.

Although the concept of natural energy subsidies has received wide acceptance among energy analysts, another feature of Odum's approach has remained controversial: energy quality. The quality of a particular fuel or energy form has been traditionally defined by the thermodynamic quantity known as "availability." The availability of an energy form is defined as its ability to do work, expressed in precise mathematical terms. Odum, however, has gone beyond thermodynamic definitions of quality to include the ways in which conversion of one energy form to another results in the "concentration" of useful energy. For example, Odum considers that fossil fuels are 2000 times more concentrated than sunlight. (Sunlight must be fixed photosynthetically by plants which, decaying over millions of years, are converted to oil or coal.) And Odum considers that electricity is about 3.5 times more concentrated than fossil fuels. (Note that these conversion factors appear to depend on the energy conversion pathways chosen for analysis.)

Because Odum's energy quality ideas have so little relation to thermodynamic concepts, this divergence must be resolved before his techniques find widespread acceptance among energy analysts. In spite of this, and other areas of lesser controversy such as evaluating the labor contribution to energy inputs, most aspects of Odum's approach to net energy analysis substantially agree with the methods of other practitioners.

4. Net Energy Analysis—A Practical Approach

Each approach to net energy analysis described thus far has advantages and disadvantages. In many applications, a practical, reasonably accurate approach that minimizes the disadvantages of each of the methods is sought. In practice, this approach tends to combine aspects of process analysis, input-output analysis, and the Odum approach.

A net energy analysis of a specific technology usually begins with the process analysis approach. Flows of energy associated with the technology are quantified from available engineering design studies or other data. Energy flows may take the form of product output, thermodynamic conversion losses, physical losses, electricity consumption, and the like. In addition, when practicable, process analyses are conducted to determine indirect energy consumption in the form of materials use.

In many instances, however, materials consumption data for construction and operation of the technology are unavailable. In this case, estimates of the dollar costs of these activities are used in conjunction with input-output tables to estimate indirect energy consumption.

Finally, when technology interacts significantly with natural systems, Odum's approach can be used to evaluate lost natural energy subsidies. In many cases, these losses are small compared with the output of the energy technology in question.

All calculations carried out in this chapter use the approach outlined above. A detailed discussion of the calculation methods for surface coal mining, coal liquefaction, coal-to-methanol conversion, and oil shale retorting and upgrading are in Chapter 5 of Volume II of this series.[4]

B. Calculations on System Components

To carry out calculations for the systems described in Chapter 1 of this volume substantial data are required not only for the energy conversion technologies but also for mining, transportation, and distribution components. The data required include information on capital and operating costs, material inputs, process variables, fuel consumption, and the like. Generally, these data are in the literature on various energy conversion technologies and other components of the energy supply system. And, in fact, we have relied on this literature in carrying out our calculations. However, this literature should be approached with caution. Many process parameters for advanced technologies are still speculative. In other, better-known areas such as transportation many conflicting data exist. Thus, care must be taken before selecting data for direct use in the energy analysis. In some cases, the data must be modified because they do not completely account for all relevant energy inputs.

As in the work on net energy analysis in Volume II, all energy inputs into the system are referenced to primary energy resources--coal, crude oil, and gas, as well as to nuclear and hydro power. This determines the total quantity of energy resources required to deliver a unit of product. Theoretically, energy inputs can be broken down into each type of resource. However, this level of detail was not considered necessary for the analysis here. (For an example of the results of the entire procedure, see Appendix A.)

These techniques and qualifications have been applied to the energy systems described in Chapter 1. The computations of energy inputs into each component of the systems are presented in Appendix D.

Table 4-1 summarizes the energy requirements for the systems components analyzed in Appendix D. The tabulations are used in calculating the total system energy requirements for each automotive fuel in a manner parallel to fuel costs calculated in the previous section. Like the cost analyses, these figures are meant to be illustrative, rather than definitive, and are based on specific technologies. Advances in technology

Table 4-1

ENERGY REQUIREMENTS FOR COAL-TO-AUTOMOTIVE FUELS SYSTEM COMPONENTS

Component	Energy Efficiency	Ancillary Energy ($Btu/10^6 Btu$ output)
Coal mine		
Surface	1.0	2.8×10^5/HV*
Underground	1.0	3.4×10^5/HV
Coal transport		
Truck	1.0	(2000/HV) x L†
Unit train	1.0	(490/HV) x L
Slurry pipeline	1.0	(760/HV) x L
Barge	1.0	(300/HV) x L
Coal conversion		
Syncrude (bituminous coal)	0.68	2.7×10^4
Syncrude (subbituminous coal)	0.63	2.7×10^4
Methane	0.56	2.7×10^4
Methanol	0.40	4.0×10^4
Fischer-Tropsch gasoline	0.30	4.9×10^4
Hydrogen	0.59	3.7×10^4
Electricity	0.35	6.3×10^4
In-situ methane	0.76	2.3×10^5
In-situ methanol	0.65	4.6×10^5
Product transport		
Crude pipeline	1.0	48 x L
Methane pipeline	$1.0 - 3.6 \times 10^{-5}L$	4 x L
Hydrogen pipeline (gas)	$1.0 - 5.2 \times 10^{-5}L$	5 x L
Methanol pipeline	1.0	30 x L
Petroleum products pipeline	1.0	15 x L
Electricity transmission and distribution	0.91	$12 \times L + 0.1 \times 10^4$
Refinery	0.96	6.2×10^4
Methane liquefaction	0.83	0.6×10^4
Hydrogen liquefaction	1.0	1.1×10^6
Automotive fuel distribution		
Gasoline distribution	1.0	0.5×10^4
Methanol distribution	1.0	0.7×10^4
Liquid hydrogen distribution	0.98	1.0×10^4
Liquid methane distribution	0.99	1.0×10^4

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*HV = coal heating value in 10^6 Btu/ton.

† = transport distance in miles.

or consideration of other fuel production possibilities (e.g., coproduction of methanol and methane) could alter the numbers in Table 4-1. However, this set of numbers, tied as closely as possible to the system components on which the cost calculations are based, will serve to illustrate the characteristics of the systems under consideration.

C. Total System Energy Requirements

The calculations of energy consumption for the production and delivery of automotive fuels is analogous to the calculation of costs. That is, the ancillary energy use by each system component is obtained from Table 4-1, and divided by the product of the energy efficiencies of all the downstream components to obtain the energy use for 10^6 Btu of delivered fuel. The total system energy consumption is then the sum of the individual components, plus the energy lost from system components with conversion efficiencies less than 1.0. This sum represents the total resource energy that must be consumed to produce and deliver 10^6 Btu of automotive fuel. Mathematically, this quantity can be expressed as follows:

$$E_{tot} = 10^6 \left(\frac{1}{\underset{i=1}{\overset{n}{\pi}} \varepsilon_i} - 1 \right) + \sum_{i=1}^{n} \cdot \left(\frac{E_i}{\underset{j=1}{\overset{i-1}{\pi}} \varepsilon_j} \right) \quad ; \qquad (1)$$

where E_{tot} is the total energy consumed by a system for 10^6 Btu of delivered energy; n is the number of system components; ε_i is the efficiency of component i; E_i is the ancillary energy requirement per 10^6 Btu output of component i; and the symbols π and Σ have their usual meanings for multiplication and summation. In evaluating the second term the last system component--fuel distribution--is labeled i = 1, and the first component--coal mining--is labeled i = n.

The calculation of the total energy consumption for each system is carried out by the same procedure described in Chapter 3 for carrying out cost calculations. The procedure has been modified to replace all dollar costs with the ancillary energy requirements, E_i. The calculation of total energy consumption for each system is then carried out as was the cost calculation, except that the first term in Equation (1) was also computed and added.

As was done in the dollar cost calculations, the program printed the maximum, minimum, and average energy consumption for specific pathways for coal conversion occurring in each crude production, gas production, refinery, or electric utility region.

D. Results

1. Total Energy Consumption

The results of the energy cost calculations are displayed in Figures 4-1a through 4-1c. Only the maximum and minimum energy consumption are displayed out of all the possibilities for each system. It is not necessary to display the results of all calculations because the results of interest are the sensitivities of the total system energy costs to the variations in each component. These are clearly indicated by the range of energy consumption displayed for each component, in relation to the range in total energy consumption displayed for each system.

The range of energy consumption for each component does not represent the absolute maximum and minimum consumption used in the calculations. Rather, it represents the range for the components of those system pathways for which the <u>sum</u> of the component energy requirements was a maximum or minimum for a particular fuel. For transportation energy consumption, however, the figures tend to represent the maximum and minimum values for transportation components. These components tend to have the most pronounced effect on the variation in total energy consumption.

Figures 4-1a through 4-1c show the flows of energy through the systems and the ancillary energy inputs required to deliver 10^6 Btu of automotive fuel or electricity. For both the ancillary inputs and the direct energy flows, two numbers are associated with each system component. The first number corresponds to the pathway with the minimum total energy consumption, and the second number corresponds to the

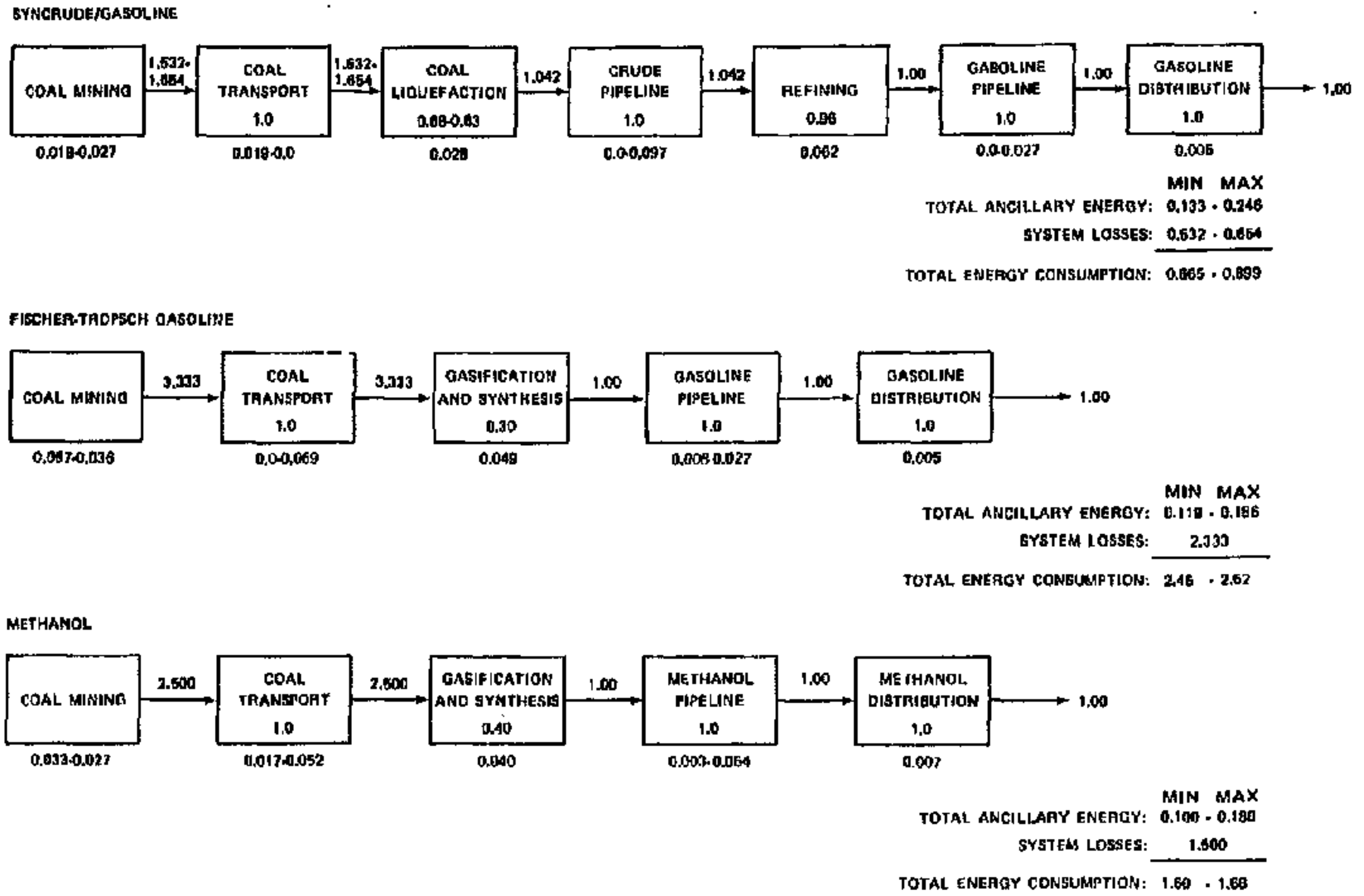

FIGURE 4-1a. ENERGY CONSUMPTION BY SYNTHETIC FUEL SYSTEMS

NUMBERS ABOVE THE ARROWS ARE ENERGY FLOWS; NUMBERS BELOW THE BOXES ARE ANCILLARY ENERGY REQUIREMENTS; ALL THESE NUMBERS ARE IN UNITS OF 10^6 Btu. NUMBERS WITHIN THE BOXES ARE EFFICIENCIES OF SYSTEM ELEMENTS.

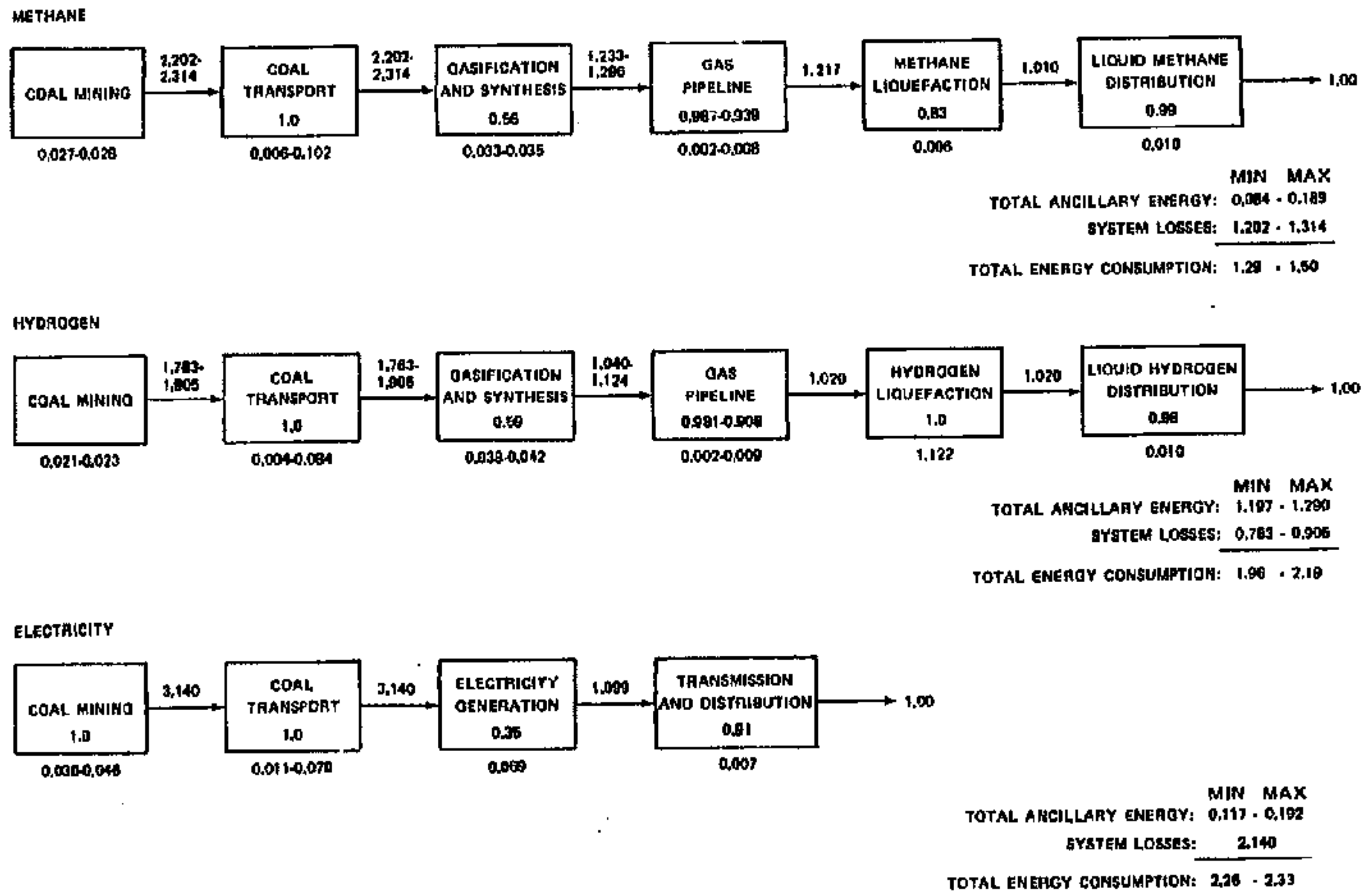

FIGURE 4-1b. ENERGY CONSUMPTION BY SYNTHETIC FUEL SYSTEMS

NUMBERS ABOVE THE ARROWS ARE ENERGY FLOWS; NUMBERS BELOW THE BOXES ARE ANCILLARY ENERGY REQUIREMENTS; ALL THESE NUMBERS ARE IN UNITS OF 10^6 Btu. NUMBERS WITHIN THE BOXES ARE EFFICIENCIES OF SYSTEM ELEMENTS.

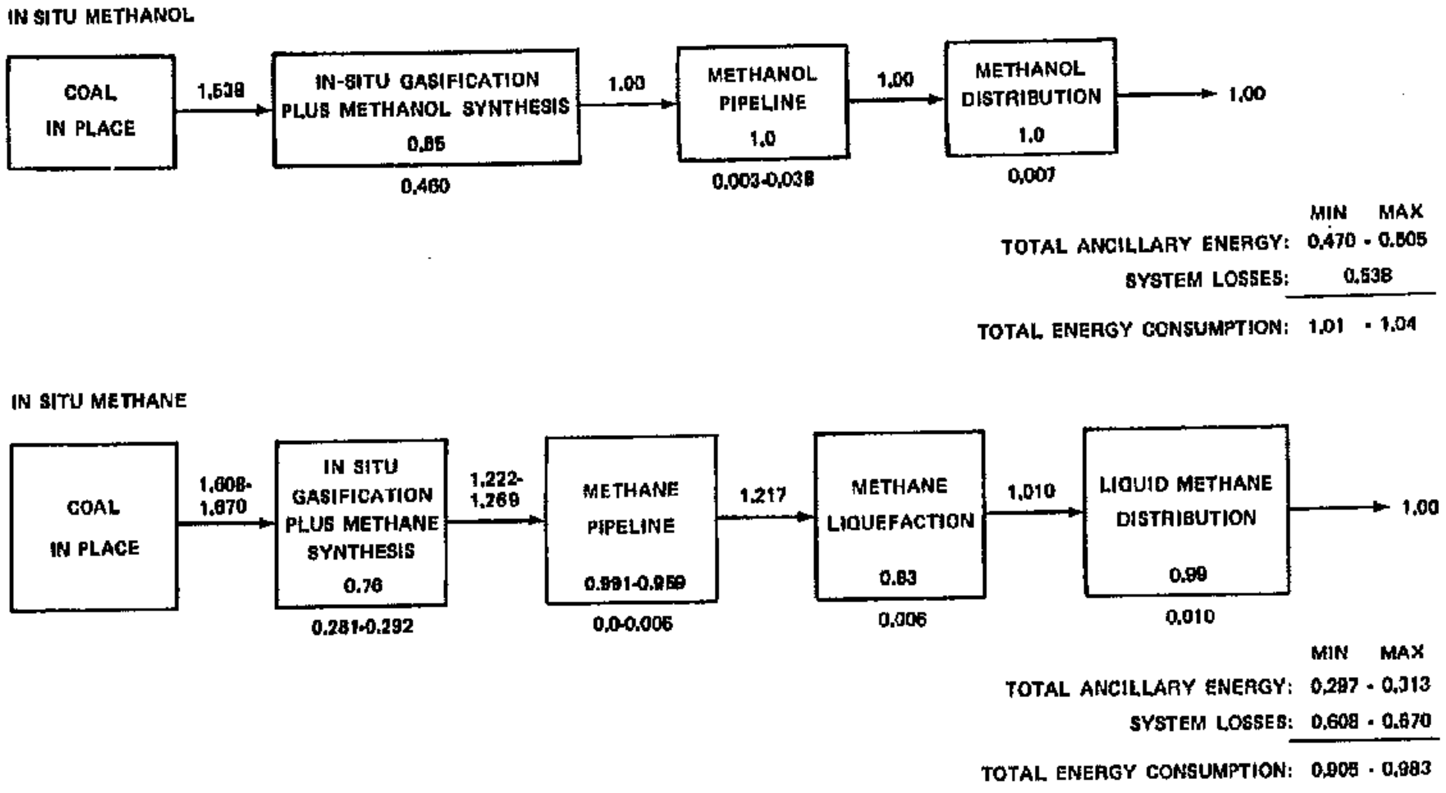

FIGURE 4-1c. ENERGY CONSUMPTION BY SYNTHETIC FUEL SYSTEMS

NUMBERS ABOVE THE ARROWS ARE ENERGY FLOWS; NUMBERS BELOW THE BOXES ARE ANCILLARY ENERGY REQUIREMENTS; ALL THESE NUMBERS ARE IN UNITS OF 10^6 Btu. NUMBERS WITHIN THE BOXES ARE EFFICIENCIES OF SYSTEM ELEMENTS.

maximum. The number within each box represents the energy efficiency of that system component.

For each system, the total energy consumption is given as the sum of the total ancillary energy requirement and the total system loss for the minimum and maximum cases.

The locations of the conversion facilities and the sources of coal for the minimum and maximum energy consumption cases are shown in Table 4-2.

Table 4-2

CONVERSION PLANT LOCATIONS AND COAL SOURCES FOR THE MINIMUM AND MAXIMUM ENERGY CONSUMPTION CASES

		Plant Location	Coal Source
Syncrude/ gasoline	Minimum	Virginia	Appalachian underground
	Maximum	Montana	Montana surface
Fischer-Tropsch gasoline	Minimum	Montana	Montana surface
	Maximum	Texas	Appalachian surface
Methanol	Minimum	Pennsylvania	Appalachian surface
	Maximum	Texas	Appalachian surface
Methane	Minimum	Illinois	Illinois surface
	Maximum	Louisiana	Illinois surface
Hydrogen	Minimum	Alabama	Appalachian surface
	Maximum	Louisiana	Illinois surface
Electricity	Minimum	Ohio	Appalachian surface
	Maximum	Minnesota	Wyoming surface

It is clear from the energy flows shown in Figures 4-1a through 4-1c that the coal conversion components represent the largest portion of overall energy consumption, ranging from 40 to 97% of the total. The exception is the hydrogen system; hydrogen liquefaction consumes more than 50% of the total, compared with 38% for coal conversion.

The contribution of coal and products transportation to the system totals varies; it ranges from less than 1% to nearly 15%.

This range indicates the influence of the varying locations in the calculations.

The sensitivity of total energy consumption to coal mining is low, as expected; coal mining energy requirements contribute 1 to 2% of the total.

Secondary conversions such as refining and liquefaction of gases can contribute significantly to total energy consumption. They represent about 15% of the total for syncrude/gasoline and methane.

The contribution of fuel distribution is uniformly small.

Figure 4-2 summarizes the energy consumption for each system and shows the variation in total energy consumption between the minimum and maximum cases. For purposes of comparison, a comparable figure is shown for the conventional domestic petroleum case. The conventional petroleum result is based on national statistics and therefore does not display a minimum/maximum variation. It is clear from Figure 4-2 that any coal-based automotive fuel option will consume considerably more resource energy than the conventional petroleum system. Coal will constitute much of the additional fuel consumed. Compared with petroleum, coal is an abundant resource. However, the large increase in energy consumption over the conventional petroleum case indicates the greatly expanded energy resource production, conversion, and transportation activities that must accompany any conversion from a petroleum-based to a coal-based transportation system.

Note that although the in-situ methane and methanol options appear attractive in relation to most others, the coal-resource base suitable for these technologies tends to differ considerably from that of the others. This is especially true of western coal, whose many deep thick seams are not suitable for recovery by conventional mining methods. However, should in-situ gasification prove successful, it may be attractive economically and energetically to provide fuels through application of this technology to seams normally accessible to conventional underground mining. This would eliminate all mining and a portion of the above-ground conversion facilities. Typically, many factors would

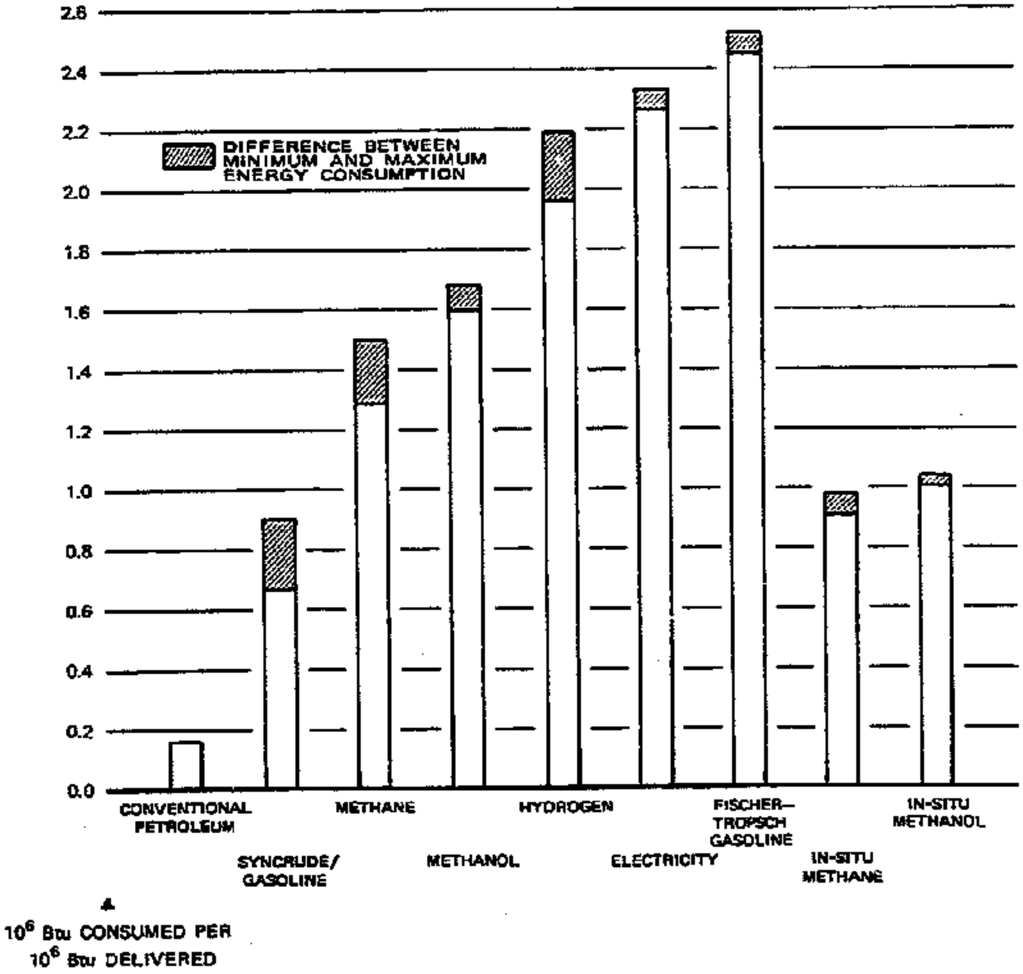

FIGURE 4-2. ENERGY CONSUMPTION BY AUTOMOTIVE ENERGY SUPPLY SYSTEMS

influence this choice, including site-related factors, environmental considerations, type of fuel desired, and the like.

2. Automotive Efficiency Effects

Because the primary function of the energy systems under consideration is to fuel automobiles, the total energy consumption must be expressed in terms of the specific end-use. In this case, the appropriate parameter is vehicle-miles of transportation. As discussed in Chapter 3, the efficiency of fuel use may vary considerably from one vehicle to the next, resulting in relative energy consumption figures considerably different from those shown in Figure 4-2.

In Figure 4-3, the vehicle energy efficiencies presented in Chapter 3 have been used to calculate the total energy required to provide one vehicle-mile of transportation, as a function of vehicle energy consumption. The total energy requirement equals the energy consumed by the vehicle, plus the energy consumed in producing and delivering this energy. As in Chapter 3, the reference case is a conventional subcompact automobile achieving a fuel economy of 30 mpg (gasoline) and meeting pollution control requirements.

The straight line plots in Figure 4-3 are based on the average total energy consumption for each fuel type. Where these lines intersect with the vehicle propulsion energy requirements, a vertical line indicates the range of total energy requirements corresponding to the minimum and maximum energy consumption shown in Figure 4-2.

As Figure 4-3 indicates, the syncrude/gasoline-powered vehicle loses its energy advantage when compared with an advanced battery-powered electric car on a Btu/mi basis. The total energy requirement for the electric car is about two-thirds that of the conventional automobile. On the other hand, among the synthetic fuel options, syncrude/gasoline is energetically superior, even allowing for considerable engine efficiency improvements for hydrogen, methane, and methanol-powered vehicles. Energetically, Fischer-Tropsch gasoline is the worst option.

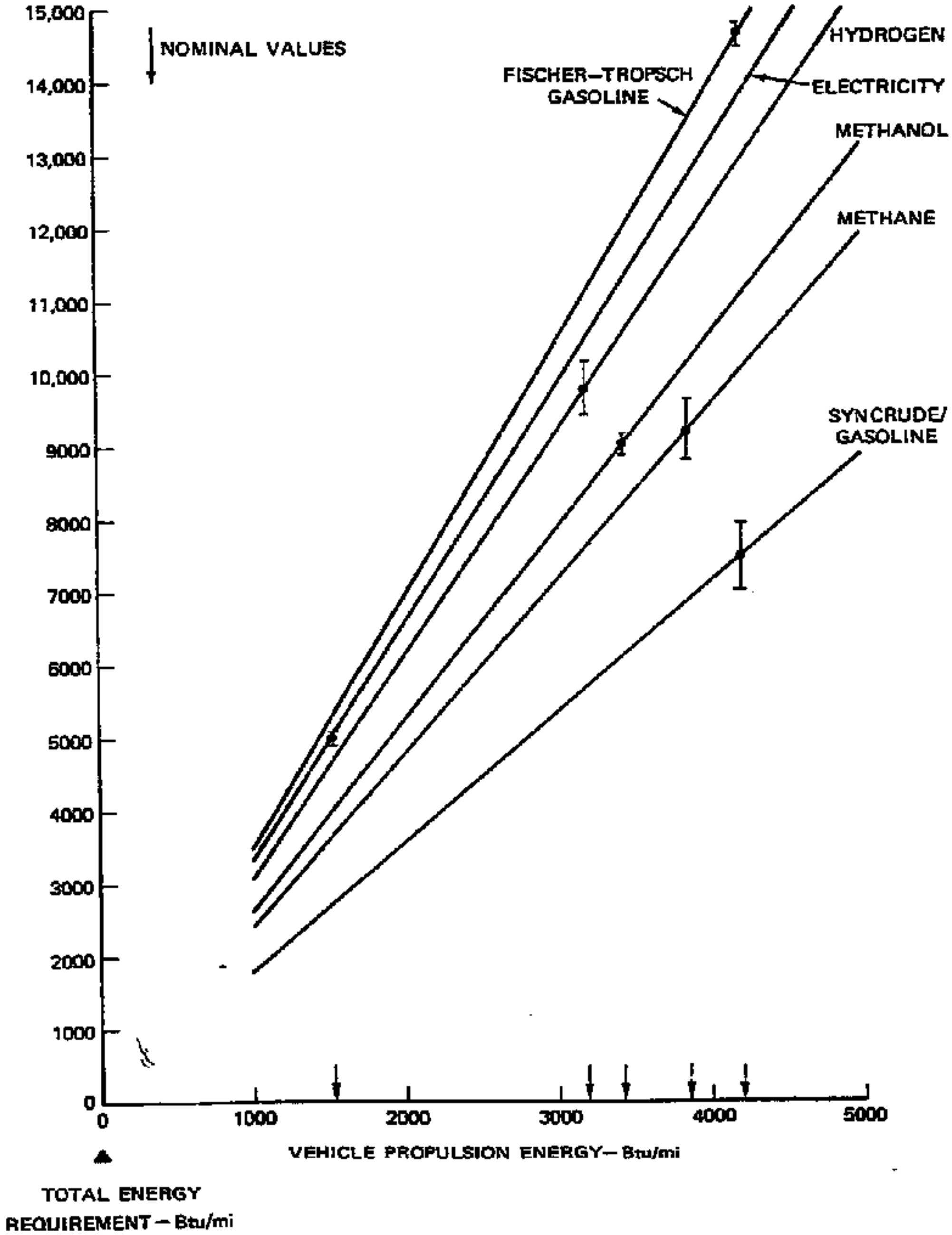

FIGURE 4-3. TOTAL ENERGY REQUIREMENTS FOR AUTOMOTIVE TRANSPORTATION

The hydrogen, methane, and methanol options fall within a narrow range of total energy consumption (9,000 to 10,000 Btu/mi) and must be considered essentially equivalent. For these options to be energetically competitive with syncrude gasoline, engine efficiency improvements on the order of 25% beyond the efficiencies shown in Figure 4-3 would be required.

Although not shown in Figure 4-3, the in-situ methane and methanol options would have total energy requirements in the range of the syncrude/gasoline option.

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