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NET ENERGY ANALYSIS OF FOSSIL FUELS AND A MATERIALS PROCESSING APPLICATION

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ABSTRACT

Two studies on net energy are discussed in this paper. The first, "Net Energy Analysis: An Energy Balance Study of Fossil Fuels", developed a methodology and net energy data for twenty trajectories of fossil fuel production systems. The systems include resources in the ground and all process steps up to energy delivery to end use.

The second study deals with net energy required to produce various materials, fabricate and distribute products from those materials, and recycle the products or materials back into the production system. The methodology and general findings are presented.

NET ENERGY ANALYSIS OF FOSSIL FUELS AND A MATERIALS-PROCESSING APPLICATION

INTRODUCTION AND BACKGROUND

Two separate studies in Energy Analysis will be discussed in this paper. The first study dealt entirely with net energy analysis in fossil fuels production, while the second applied this information to an analysis of the energy costs of producing and recycling some products made from various natural resources.

The first study was entitled "Net Energy Analysis: An Energy Balance Study of Fossil Fuel", and was conducted under the auspices of the Colorado Energy Research Institute by a team managed by the principal author of this paper. This study was conducted in 1975 and 1976, at a time when both the concept and methodologies of net energy analysis were ill-defined and rudimentary.

We organized the study for several reasons. For one thing, there was a lot of apparently illogical information in the press and in some poliltical circles declaring that some fossil fuel production systems were "net energy losers;" they required an energy subsidy which exceeded the energy product of the system. However, we could find no solid information to support those claims. Hence, we felt that it was important to examine the concepts of net energy and to develop the best possible data and information on the subject.

Second, with the legitimate national concerns about energy planning, we wished to examine the subject of net energy balances of fossil fuels to see if it might shed any new light on the exceedingly complex subject of the nation's energy decisions. Congress had placed some requirements on the Energy Research and Development Administration for net energy analysis, although the Congressional mandate was predicated upon only the limited perspective of a few people. Also, there was some discussion in state legislatures of requiring net energy analysis in plant siting. Some people were even espousing energy as the social "numeraire", or basis of the mensuration of value of goods and services. New technologies were being explored which could make vital contributions to our energy supplies, but some might be more meritorious than others in terms of their net contribution. The efficient use of energy and materials is unquestionably a major social concern.

The second study which will be discussed in this paper was conducted by the Colorado School of Mines Research Institute for a large industrial corporation. The purpose was somewhat different. Corporate management desired information on the quantities and types of energy which are required to bring their product to market. Furthermore, they wished to know what the energy requirements would be if recycling of materials and products were to be achieved, considering various recycle rates. Such information could be very useful in choosing between options in product types, materials for the products, production systems, materials and product recovery and reuse, and control and efficient use of energy in the entire system. It could alert management to some possible pitfalls and danger signals. To accomplish this study, it was essential to have reliable information on the net yields of the energy systems upon which the various materials and product systems depend.

In both studies, then, the ultimate concern and analytical process dealt with resources in the ground, and the net energy finally represented by the systems of delivering consumables to the consumer. A fundamental premise upon which both studies were founded was that real-life data, not theoretical or abstract information, must be acquired and utilized in the analyses.

NET ENERGY ANALYSIS OF FOSSIL FUELS

The Colorado Energy Research Institute (CERI) study, as mentioned, arose partially because of speculation about energy "subsidies" from society which were needed to produce fuels, and which, in some cases, were "hidden." In direct economics, the inputs into energy production are indeed hidden, because the purchaser of energy does not know what portion of the purchase price represents costs, labor, materials, research, financing, energy, foreign materials in catalysts, the Corps of Engineers, or what-have-you. Some people maintained that energy production systems disrupted vast quantities of energy in natural ecosystems, even to the point of immorality. Even traditional "efficiency" measurements, let alone economics, do not identify and measure these indirect energy inputs, subsidies and effects.

The entire subject involved energetic debate amongst the cognoscente, with more heat than light as a result of the debate.

Objectives

The objectives of the project were:

A. To provide reliable, objective, credible information to government and industry on the net energy inputs and outputs of western fossil fuels energy systems;

B. To provide a workale methodology, which could be used in subsequent expanded net energy studies, and which was oriented towards the potential use of net energy information in decisions about resource production;

C. To provide the best possible documentation of data related to net energy;

D. To discuss and describe the usefulness and limitation of net energy studies and their potential values in decision-making; to discuss philosophy and issues pertaining to net energy studies.

Methodology

Energy analysis represents a broad field of study dealing with the development and use of all aspects of energy in human society and its environment. Net-energy analysis, a more limited field of study, deals with the analysis of the energy made available to society by energy production processes after the deduction of energy lost to society as a result of the processes.

Because of the rudimentary state-of-the-art of net energy analysis, we commenced by devoting attention to a methodology. We recognized that the methodology must relate to issues surrounding the subject. Also, we realized early in the study, that "net energy yields" can be defined in several ways, and that there are several major concerns or issues to which the general title of "net energy" might apply. We defined three major issues.

Issue 1:

> How much energy is required from the industrial component of society to "drive", or establish and operate an energy production process, relative to the energy yield of the process.

Issue 2:

> In extracting, processing, moving fossil fuels to provide energy to end users, what final yields do we get relative to losses of the total energy of the recovered fossil fuel resource and of the industrial energy which is needed t establish and operate the fossil energy production systems?

Issue 3:

> For a given output of fossil fuel energy for end use, what total amounts o the gross fosil fuel resources in the ground and industrial energies are necessary to establish and operate the system?

The issues of the finiteness of fossil fuel resources and the rate of depletion ar concern to society. Hence, we have included a step in our methodology which relates these issues. It describes the amount of gross fossil fuel resource in the ground which affected by recovery with present technology and economics. Future generations ma forced to recover some of the presently-unrecovered resource at a high cost and ener investment. For today's society, the "capital stock" of fossil fuels is depleted and in a sense degraded by the use of part of it.

The next concern of the study was defining boundary conditions which would le to analytical findings a relevant to the major issues.

Because energy analysis is a fairly new technique, various investigators have u different ground rules. Some have included human energy of employees, using either

metabolic energy of about 12,000 Btu's per person or "life style" energy of about 960,000 Btu's per person per day. Others have included the energy in ecosystems which are disturbed by industrial processes. We excluded these and are accounting only for "industrial energy." For one thing, early calculations showed us that these quantities are so small that they get lost in the noise of the data. Also, their inclusions must be based on a number of philosophical points which did not appear valid to our particular group of investigators. (A full discussion of these matters can be found in the CERI report.)

We selected a system boundary as shown in Figure 1. This boundary includes all the steps of locating and extracting fossil fuels through processing, converting and transporting them as energy delivered to end users. It is recognized that some energy is cycled back into the continued operation and expansion of the fossil fuel production system. Some of this energy must be cycled into the production of materials for the system's construction and operation. The system depends not only on direct inputs of energy and materials, but on indirect inputs as well. The system also depends on the resource in the ground. This is as integral to the system as the mine or well which extracts, or the transportation system which delivers it to the user. Hence, the in situ resource is included in the boundary.

We recognized that there are number of different paths through which a fossil fuel can be put to change its character and deliver it in a usable, socially desirable and economic form to users. We call each of these possible path ways a "trajectory". (See Figure 2).

Each trajectory has a number of steps, which we call modules, and some modules (examples are surface mining of coal or pipeline movement or liquids) are common to a number of trajectories. Hence, we decided to analyze modules and combine them into trajectories.

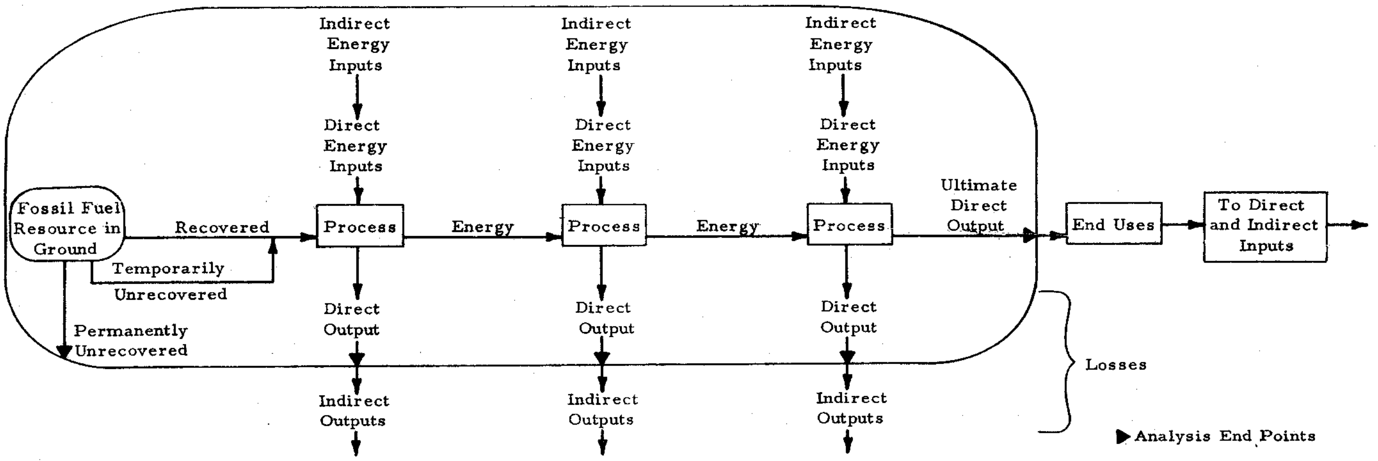
A single module has inputs and outputs as shown in Figure 3.

The inputs are:

> **PRINCIPAL ENERGY:** Fossil fuel to be processed or transported.
>
> **EXTERNAL ENERGY:** Energy which is required from outside to operate the process and to make the materials needed to build and operate the processing system.

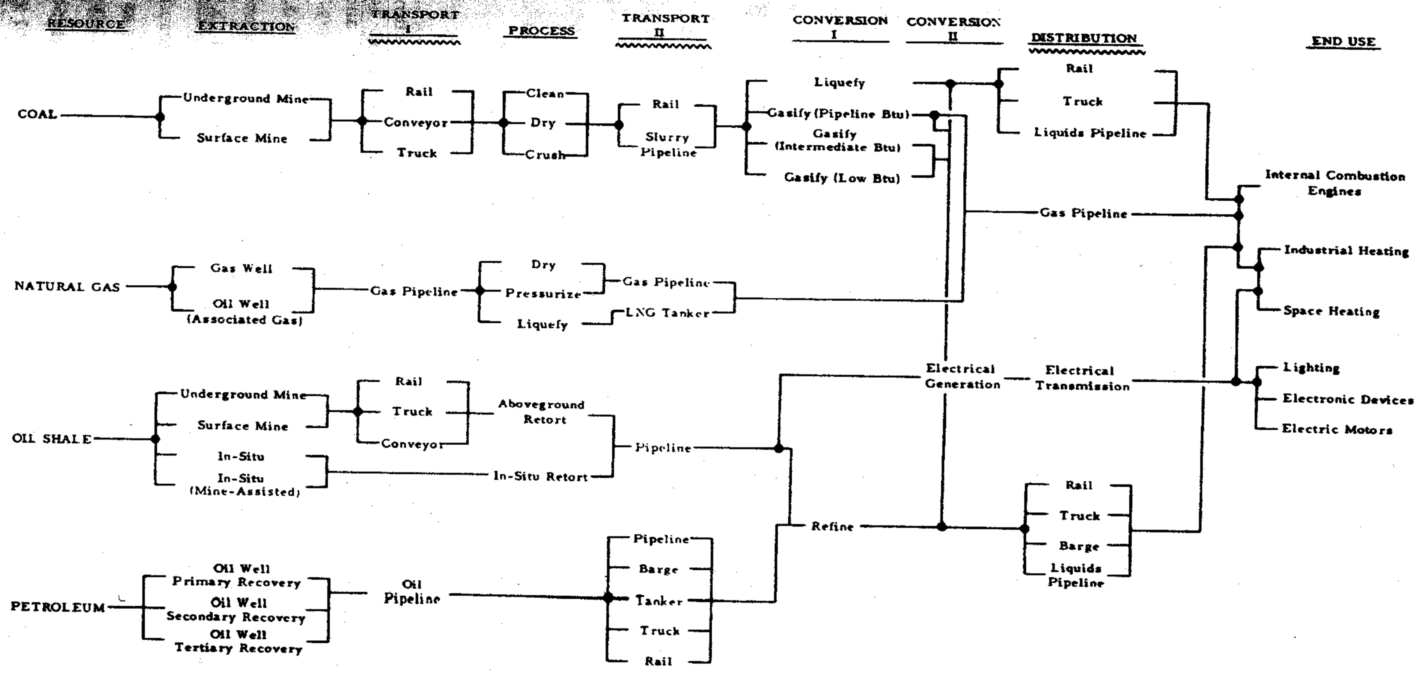
The outputs are:

> **ENERGY PRODUCT:** Processed or transported energy delivered from the process.
>
> **ENERGY LOSS:** Energy unavailable for further use as a result of the process; this can include physical losses, unrecovered resources in extraction, internally



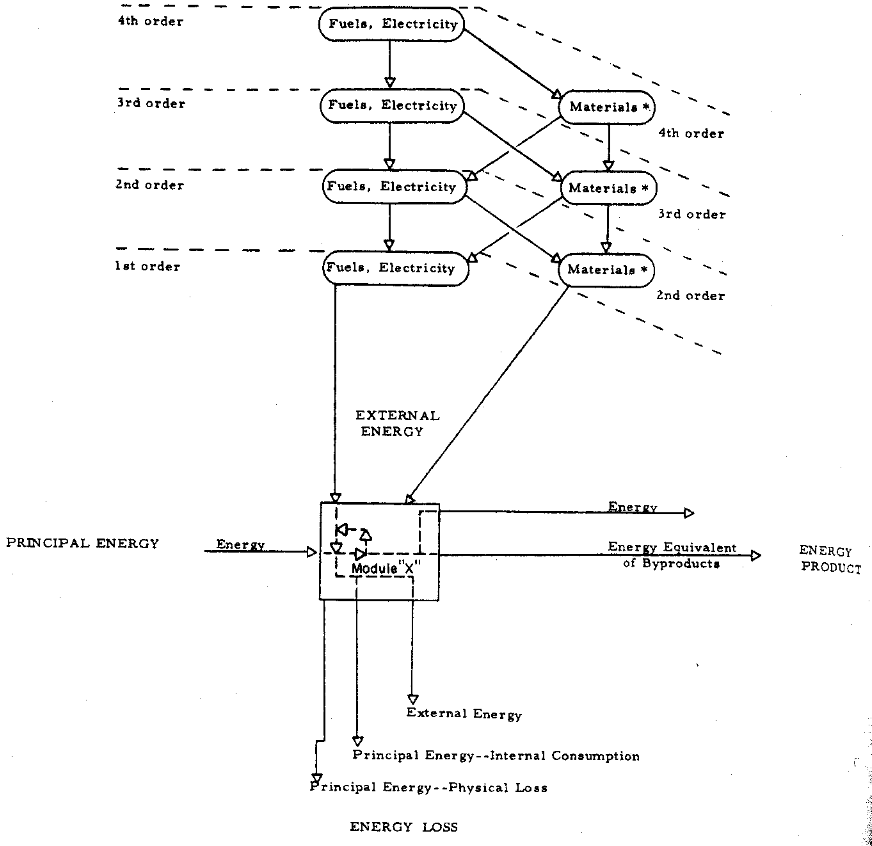
	Indirect Inputs	Direct Inputs	Direct Outputs	Indirect Outputs
In Study Boundary	Energy Materials	Energy Materials Water	Energy, Heat Materials Usable Byproducts Unusable Salvage	
Outside Study Boundary	Urban System Infrastructure Services Housing Social System Intellect Ecosystems Food Systems Financial Government Systems Hydrological Systems	Labor Intellect Financies Land	Finances Water	Ecosystem Distruption Health Social Systems Economic Systems Land Use Food Systems

FIGURE 1. *ENERGY ANALYSIS SYSTEM BOUNDARY*



● Option points.

FIGURE 2. FOSSIL FUELS ENERGY PRODUCTION GENERALIZED FLOW DIAGRAM



Materials include raw materials, containers, machinery, consumable manufactured items (catalysts, lubricants, chemicals, process additives, etc.) tools, pipelines, wiring, construction materials, and road materials (asphalt, cement, tar, steel, etc.)

FIGURE 3. ENERGY FLOWS - GENERALIZED MODULE "X"

consumed energy, and external energy.

The losses are somewhat different for each module, and will change as technology improves in the future. This study assumes technologies which might be on line by the early 1980's, and the economics will not radically change so that inputs and outputs of any module would change significantly.

The final output is identified by energy type (gas, gasoline, coal, electricity) as a generaly indicator of the quality of the energy. "Quality", as we defined it, refers not only to thermodynamic properties of different forms of energy but also to social value factors such as locations, transportability, storability, utility, etc. Energy qualities are as important as energy quantities. The qualities create the social preferences which are a cause of variations between dollar costs and net energy yields of various end products of energy. Modern society needs various types of energy with different qualities. It should be noted that quality changes as energy is processed, and that external energy inputs are comprised of different qualities of energy. Hence, a trajectory represents quantitative measurements (British thermal units, for instance), but is qualitatively a mix of different types of energy.

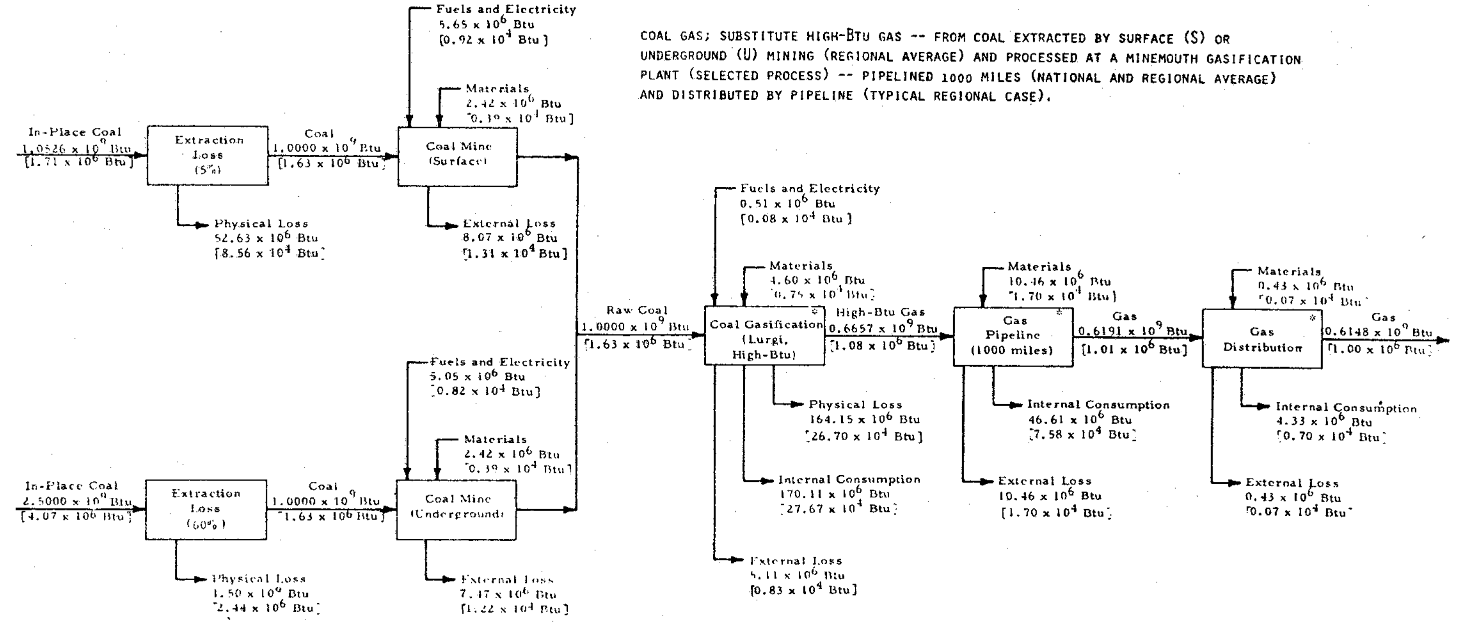
Modules were analyzed for materials and energy balances. Some materials in construction and operations could not be identified except in dollar terms. These were converted into energy equivalents using national data on energy per dollar of output for standard industrial codes from an input-output analysis done by Drs. Herendeen and Bullard at the University of Illinois at Urbana-Champaign. Indirect energies were calculated by an iterative method using data from an initial run of trajectories which had direct inputs only, and combined with national average data on energy mixes.

Also, some processes can operate on either external energy or on energy generated within the process. This poses an energy accouting problem as regards the first issue, that of output compared to external energy. However, for our modules, we used the most common or anticipated energy flow.

Findings: Data

Figure 4 shows a typical trajectory which we analyzed. Data are presented both for (1) 1.0 X 10^9 Btu inputs of principal energy and (2) in brackets, normalized to 1.0 X 10^6 Btu output.

Table 1 summarizes the data for several trajectories. Several points stand out. First, external direct and indirect energies range from about 2.6 percent for coal (used directly as a fuel) to about 26 percent for oil shale to electricity. This number is about 4 per cent for natural gas and coal gasification and from 10 to 16 per cent for most of the other processes, including electrical production from most fuels. In no case is it necessary to invest external energy anywhere near the amount of energy which is



COAL GAS; SUBSTITUTE HIGH-BTU GAS -- FROM COAL EXTRACTED BY SURFACE (S) OR UNDERGROUND (U) MINING (REGIONAL AVERAGE) AND PROCESSED AT A MINEMOUTH GASIFICATION PLANT (SELECTED PROCESS) -- PIPELINED 1000 MILES (NATIONAL AND REGIONAL AVERAGE) AND DISTRIBUTED BY PIPELINE (TYPICAL REGIONAL CASE).

Note: [ ] denote numbers normalized to 1.00 x 10^6 Btu final output.

*Option 1: Use of internally converted energy in lieu of external energy.

FIGURE 4. SELECTED COAL GASIFICATION TRAJECTORY

TABLE 1

SUMMARY OF SELECTED TRAJECTORIES NET ENERGY ANALYSIS OF FOSSIL FUELS

(in Btu units)

Selected Trajectory	Primary Final Product	Initial Resource Required	Unrecovered Resource	Initial Process Input	Total External Losses	Total External and Process Losses	Total External and Process Losses, and Unrecovered Resource	Final Output
Natural Gas	High-Btu Gas	116	--	116	4	20	21	100
Coal (S) Gas	High-Btu Gas	171	8	163	4	68	78	100
Coal (U) Gas	High-Btu Gas	407	244	163	4	68	313	100
Petroleum Gasoline	Gasoline	333	222	111	10	24	249	100
Oil Shale (S) Gasoline	Gasoline	198	40	158	16	85	128	100
Oil Shale (U) Gasoline	Gasoline	316	158	158	15	84	246	100
Coal (S) Liquefaction Gasoline	Gasoline	157	8	149	15	74	89	100
Coal (U) Liquefaction Gasoline	Gasoline	373	224	149	15	74	305	100
Coal (S)	Coal	105	5	100	3	4	12	100
Coal (U)	Coal	250	150	100	3	4	157	100
Natural Gas Electricity	Electricity	370	--	370	12	283	285	100
Coal (S) Gas Electricity	Electricity	544	28	516	11	483	464	100
Coal (U) Gas Electricity	Electricity	1,291	775	516	11	434	1,212	100
Petroleum Electricity	Electricity	1,044	696	348	10	263	966	100
Oil Shale (S) Electricity	Electricity	616	123	493	28	446	575	100
Oil Shale (U) Electricity	Electricity	984	491	493	26	444	942	100
Coal (S) Liquefaction Electricity	Electricity	567	29	538	11	455	488	100
Coal (U) Liquefaction Electricity	Electricity	1,346	808	538	10	457	1,268	100
Coal (S) Electricity	Electricity	354	17	337	11	251	279	100
Coal (U) Electricity	Electricity	842	505	337	11	252	767	100

S = Surface Processing
U = Underground Processing

delivered as usable energy.

Second, in terms of the initial input of principal energy, the losses and external energies involved in the processing, and the final net yield or output, it is clear that all electrical trajectories have high input requirements. Synthetic liquids from coal and shale are about equal in this respect, and are about 50 per cent larger than the traditional fuels of oil, gas and coal.

Third, the gross fossil fuel resource which is affected by the demand for 100 units of energy by the user varies greatly. Where mining is involved, this gross resource is much larger for underground mining than for surface mining, due to different recovery efficiencies. It is much lower for surface coal-to-electricity, which in turn is lower than surface coal-to-gas-electricity. Surface-mined oil shale to gasoline gives a better net yield from the gross resource than does petroleum-to-gasoline, although tertiary recovery would make these two trajectories close to equal.

The three fuel systems of oil shale-to-gasoline, coal-to-gas, and coal-to-gasoline require about equal gross resources when either surface mining or underground trajectories are compared with each other for the three systems.

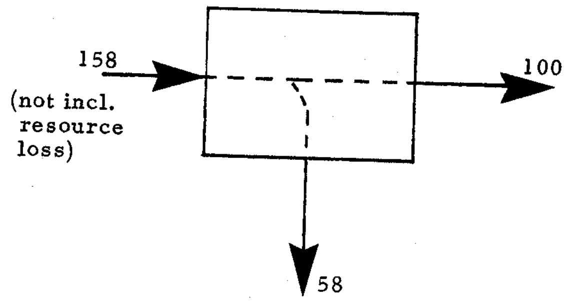
It is interesting to compare net energy analysis with traditional measurements of engineering efficiency (the "first-law" efficiency, as it is now called.) Figure 5 compares the two. Engineering efficiency is commonly used for various thermodynamic cycles such as the Otto, Rankine, and Carnot, and for specific pieces of hardware such as the "grate efficiency" of a boiler coal combustion chamber. These efficiencies often vary with the ratio of actual load to rated load. Using the overall oil shale-to-gasoline trajectory as an example, Figure 5 gives (in the top figure), the engineering efficiency as a ratio of energy out to energy in, expressed as a percentage. The bottom part of Figure 5 gives the "energetics" or net energy efficiency. The output of energy is divided by total inputs, including external energy, and expressed as a percentage. The engineering efficiency of 63% is about 15% higher than the energetics efficiency of 55%.

This figure also, at the bottom in brackets, shows the net yield of usable energy product 63 units from the gross resource 100 units after deducting the external energy requirements and losses due to processing the oil shale. The net yield is 100-37-15 = 4 units .

Ratios can also be used to express the data. However, we do not recommend tha ratios be used, as they can be misleading. Also, a small change in the denominator causes a large change in the ratio. Furthermore, unless there is a standardized groundrule on expressing data in ratios, there will be a plethora of confusing approache which will be developed to prove some particular point to advance a cause or philosoph We recommend that, if ratios are used, they be consistent with Figure 6. Ratio R_1 dea with the first issue of comparing the energy product to the external energy. Ratio R_2

"FIRST LAW" EFFICIENCY

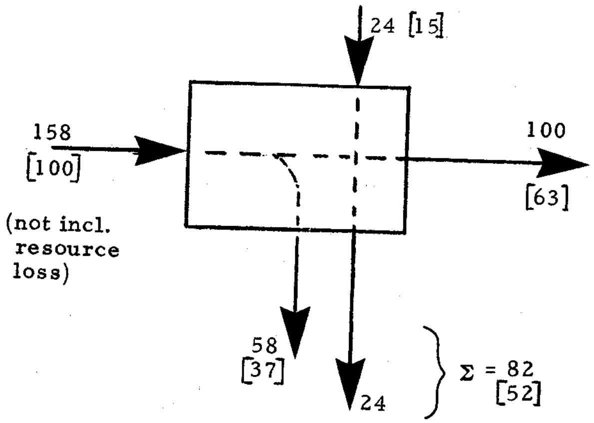
(Oil Shale Example)



EFFICIENCY $= \frac{100}{158} = 63\%$

"ENERGETICS" EFFICIENCY

(Oil Shale Example)

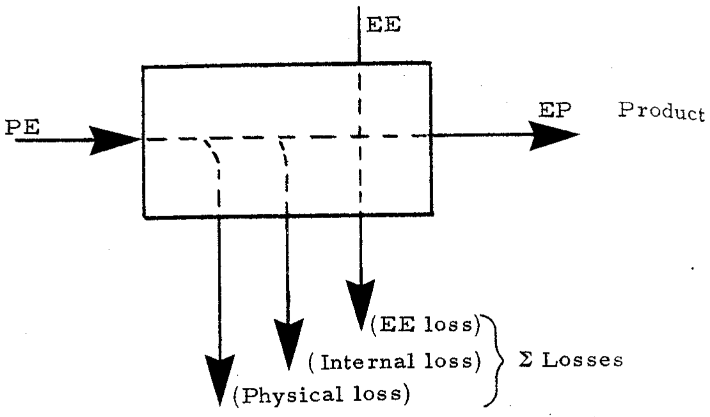


EFFICIENCY $= \frac{100}{182} = 55\%$

[NET YIELD = 100 - 52 = 48 or 48%]

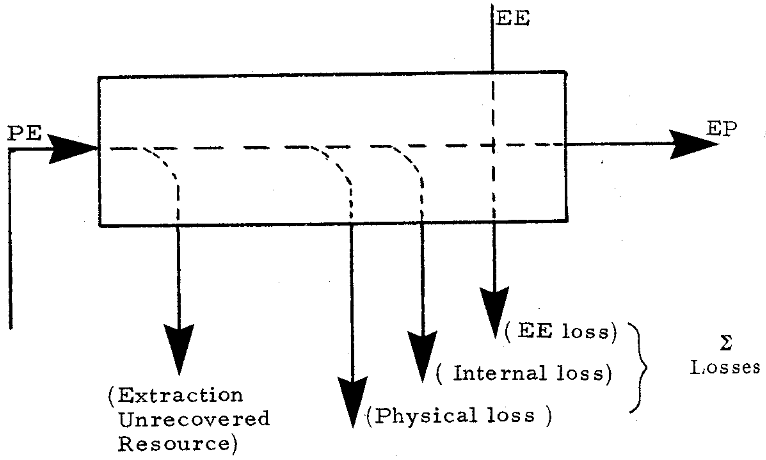
FIGURE 5.

RATIOS



$R_1 = \frac{EP}{EE}$ (External Subsidy Issue)

$R_2 = \frac{EP}{\Sigma \text{ Losses}}$ (Engineering Efficiency Issue)



$R_3 = \frac{EP}{\Sigma \text{ Losses}}$ (Resource Process Issue)

FIGURE 6.

addresses the second issue of output compared to process and external energy losses. Ratio R_3 is concerned with the third issue: given a gross resource of fossil energy in the ground, with current technology and economics, how much is netted out by society in using the resource? Note that R_3 includes the external input.

As mentioned, when we started the study, it appeared that the first (R_1) issue was the most important one. However, when we finished, most of the team felt that the third (R_3) issue is more important. For one thing, the external energy inputs are geneally fairly small. We do not know what is intolerable in this respect, but in the absence of further studies, oil shale-to-gasoline, and coal-to-gasoline, do not appear to have unacceptably high external energy requirements. The only one which appears to be a questionable technology is oil shale-to-electricity, with 28 units of external energy per 100 units output.

However, the trajectories vary greatly in gross resource requirements per 100 units out. As shown in Table 1, this ranges from 116 for natural gas as gas to 1,346 for the underground coal-to-liquid -to-electricity trajectory. We feel that trajectories should be fostered to maximize the output per unit of gross resource, recognizing that while natural gas and petroleum are our most critical resources, even coal and oil shale are finite resources.

The issue of end use efficiency was not one which we addressed, and end use was not included in our boundary. However, this is very important. A quick example will demonstrate the importance of end use efficiencies. Energy should be used wisely to meet social goals in the end uses. Given the goal of providing 429,000 warm houses for the health and comfort of the occupants, we could meet that goal with a number of different trajectories and end-using devices. Let us compare two: syngas from coal burned in furnaces at 60% efficiency, and electricity from coal for baseboard resistance heating at 100% efficiency. The former would take advantage of the existing end use infrastructure of home furnaces, obviating the need for capital investments by homeowners to replace furnaces. Also, the 60% efficiency of gas-fired furnaces can undoubtedly be improved. The following comparison can be made:

	Energy: 10^{12} Btu/year Gas	 Electricity
Initial Resource Required	127	151.9
External Energy Input	3	4.7
Total Losses	56	113.7
End Use of Energy	74	42.9

For this example, there are a number of real-life factors which must be considered in decisions. These include economics, governmental energy price regulation, existing infrastructure in energy production-distribution-end use system, consumer costs, environmental factors, water resources, and so forth. We leave the consideration of policy options to the reader.

We also developed a graphic approach to comparing trajectories. Figure 7 shows a key diagram for the graphic display of trajectory, and Figures 8, 9, 10 and 11 are different trajectories portrayed at the same graphic scale. The cross-hatched loss is the unrecovered resource, as discussed in Issue 3 (R_3); it is included in "Input 3" of the figures, and excluded in "Input 2", which deals with Issue 2. If these figures are overlaid on each other, the relative magnitudes of the trajectories becomes obvious.

Conclusions

What conclusions can we draw from all of this?

(1) Net energy analysis should be further developed and tested as a planning tool to supplement economic, technological and environmental information.

(2) Specific and useful comparisons can be made between various fossil fuel production processes.

(3) Indirect external inputs of energy to produce the materials of fossil fuel systems are quite small. Therefore, expensive techniques to refine this data for net energy analysis are not warranted.

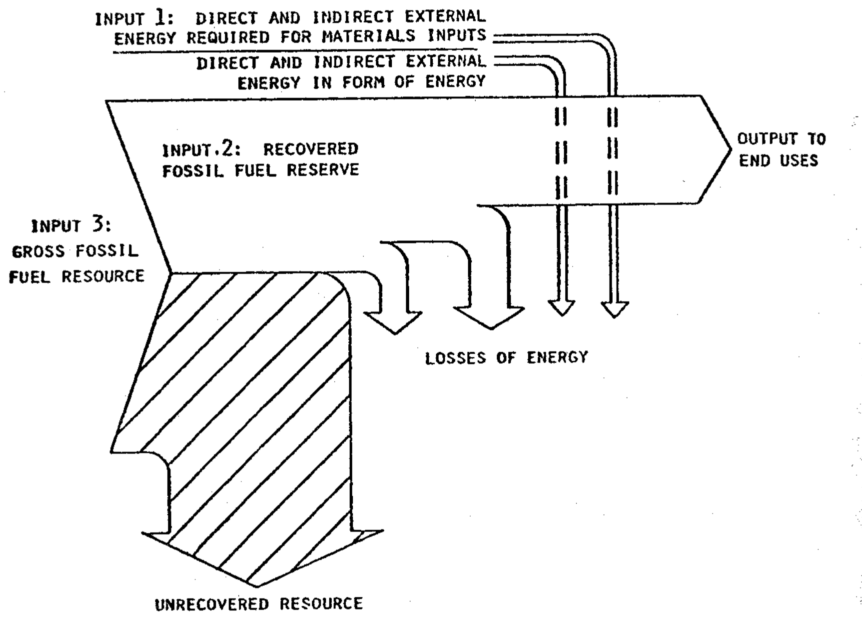


FIGURE 7. KEY DIAGRAM: ENERGY BALANCE OF TRAJECTORY

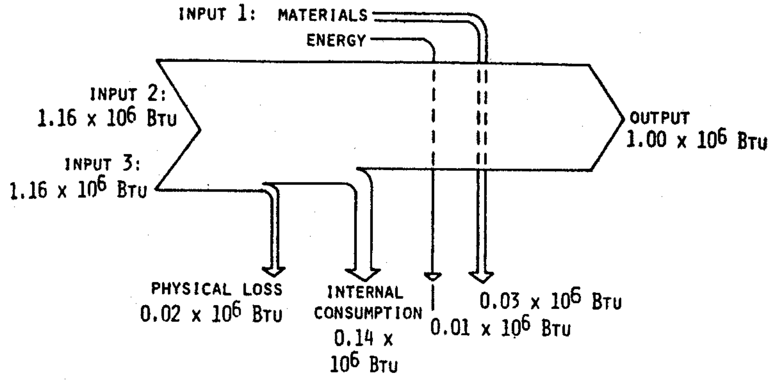


FIGURE 8. SUMMARY: NATURAL GAS

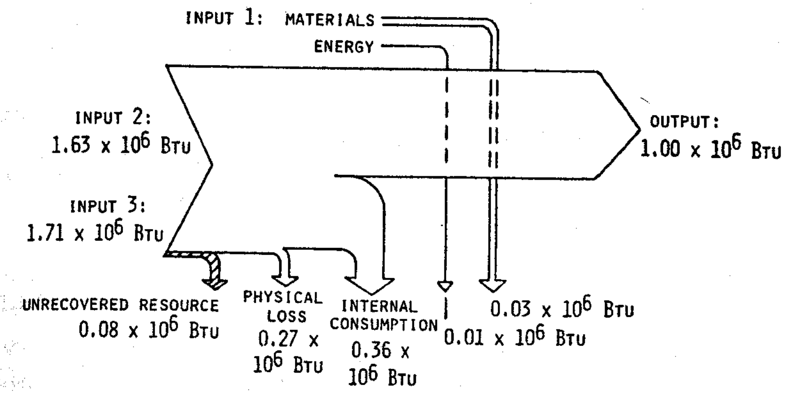


FIGURE 9. SUMMARY: COAL GASIFICATION (with surface mining)

(4) There do not appear to be any significant "hidden subsidies" in direct or indirect external inputs.

(5) Net energy analysis should not be used as the primary decision factor either to proceed with or to delay synfuels research efforts. Other factors than energy balances must influence responsible decisions and they will generally carry more weight. These factors include: (1) economics, (2) environment, (3) national security, (4) energy mix, end use efficiencies and substitutability, (5) lead times, (6) transportation capacities, (7) institutional restraints such as governmental regulations and incentives, (8) availability of needed materials, (9) available water, (10) local attitudes and socio-economic impacts, (11) employment needs, and (12) needs for energy.

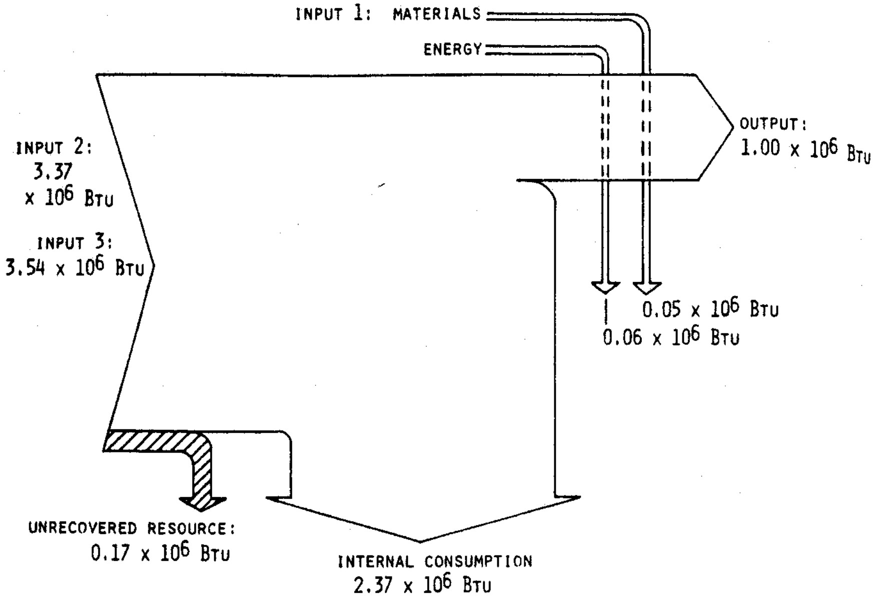


FIGURE 10. SUMMARY: COAL - ELECTRIC (with surface mining)

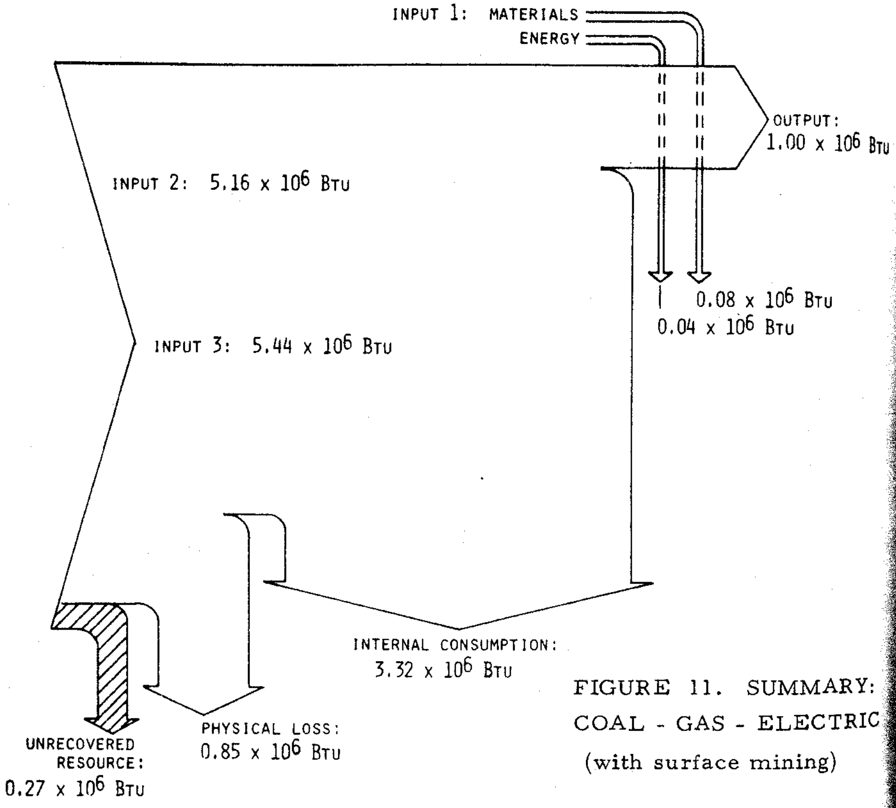


FIGURE 11. SUMMARY: COAL - GAS - ELECTRIC (with surface mining)

(6) Scenarios for very high electrical growth should be re-examined in the light of net energy information. For a given output, they result in higher external energy inputs, more resource base utilization, and higher losses than the direct combustion of fuels.

(7) Direct combustion of coal, using methods such as the fluidized bed, should be simulated. There is also some substitutability in end uses between electricity and direct combustion which should be considered.

(8) Rapid growth of some types of energy development may require such high reinvestments of external energy that their net yields to society may be very low until the growth rate slows. This dynamic analysis has not yet been analyzed but warrants further examination.

EXAMPLE OF
ENERGY ANALYSIS IN MATERIALS PROCESSING

Because of the proprietary nature of the study, the data and some of the clusions will not be discussed. However, the overall methodology and some clusions can be presented. The basic objectives of the project were mentioned in the duction and Background.

thodology

As with the fossil fuel study, the entire system of interest commences with urces in the ground: iron ore, bauxite, petroleum, sand, soda ash, and so forth. The ns of extracting the ores, recovering the minerals values, converting these to usable erials, fabricating the materials into products, distributing them, recovering the used uct, and reprocessing either products or their materials for reuse, were all included. each of these steps, all energy-direct and indirect traced back to resources in the nd - was identified as to type and quantity. One important departure from the fossil methodology was made in this study. We excluded all the energy requirements of materials required for both the energy production systems and the materials essing systems. In other words, we did not include the energy sequestered in the plants, refineries, steel mills, trucks and railroad hardware, fabricating plants, and rth. The CERI study had indicated that the quantities of such sequestered energy relatively small, and the differences in sequestered energy between systems would ry small. Secondly, this aspect of energy was not especially relevant to the options ble to corporate management.

Energy must be expended when a material is extracted from nature is processed, transported. As a material moves "downstream" through a series of processing it represents (or has necessitated) an accumulation of energy expenditures. This y embodied in the material as a result of processing is called "sequestered" energy.

It is important to note that it is not energy in the material itself unless the material has an inherent fuel value in combustion. A petroleum-derived chemical usually has such an energy value. Steel, aluminum, glass, bauxite, limestone, and similar materials do not have a fuel value, but their processing still represents energy expenditures. Hence, the energy requirements of finished products include fuel values in some cases and expended processing energy in all cases to represent the total sequestered energy.

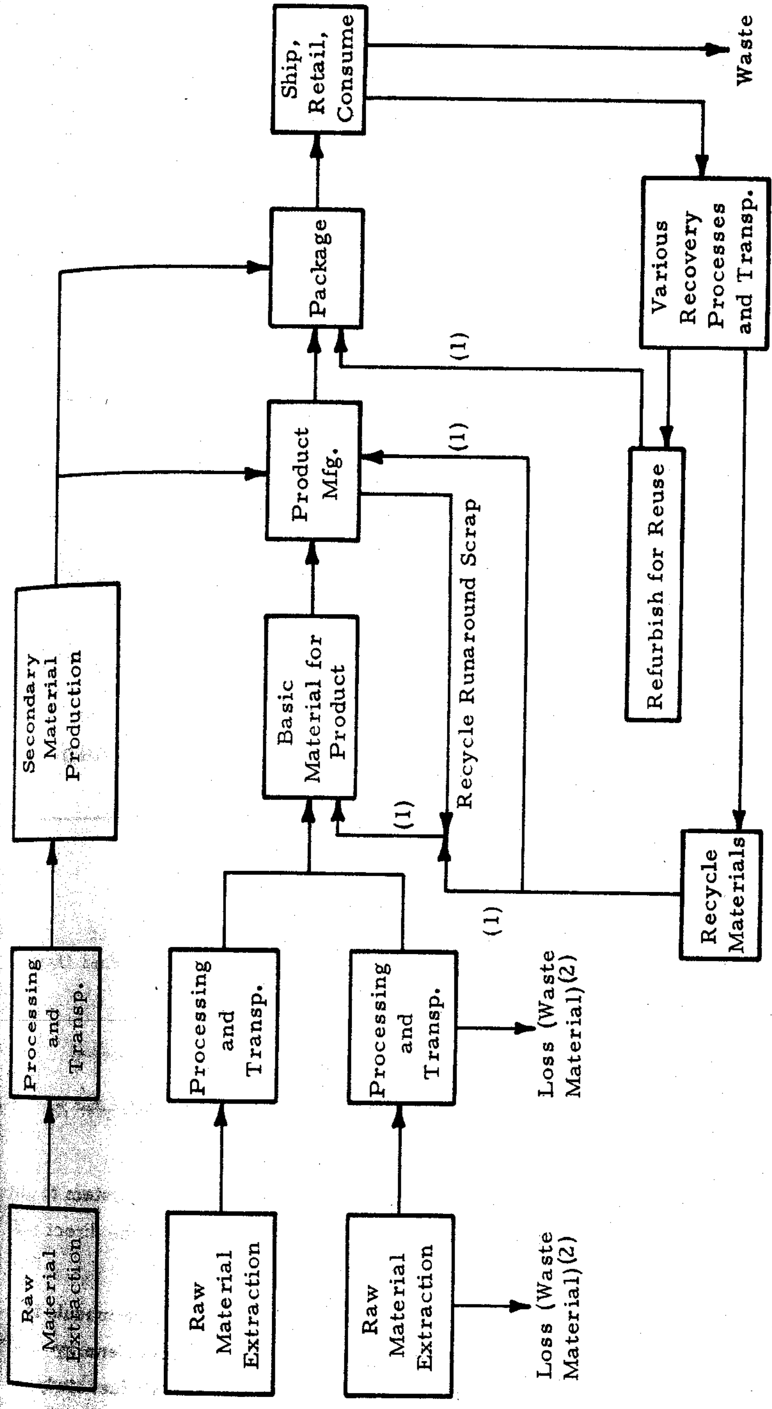
Processing of material usually involves some loss of the material. Rolling metal sheet entails some trimming off of metal; melting involves a stack loss of some of the materials in the batch. In both cases, the "lost" material has had energy invested in bringing it into the particular process. Hence, every loss of material means that either (1) the lost material represents a loss of sequestered energy or (2) the usable remaining material must have assigned to it the sequestered energy of both usable and lost material. Obviously, efficient use of material (low waste, lightweighting) is directly equivalent to efficient use of energy.

In order to quantify the invested energy in a materials processing system, it is first necessary to describe all the steps in processing and transporting materials through the system. It is then necessary to quantify the flows of material through the system. We have called each step in the system a "module." Each module has a material, or several materials, entering as inputs, and a principal material output which becomes an input to the next module. There will probably be losses of material from the module. In some cases, these may be recycled back to an earlier module to reenter the materials flow, or they may be usable byproducts or coproducts.

Figure 12 is a generalized depiction of an entire material system. It starts with the extraction of all the necessary raw materials. It includes their processing and blending into a material suitable for making the product. Some material recycles have already occurred by this point. The system then proceeds with product fabrication, packaging, shipping and retailing. The system continues in tracing the fate of the products: litter, solid waste, or recycling somewhere into the earlier flows of the system.

The various systems are all partially closed loops to some degree. In all cases some materials cycle through the system. These may cycle at various points out of back into the main materials stream. Recycling of the finished product is not the only feedback in some systems. Materials may drop out of the loop completely, and inputs new materials at the upstream end of the loop are needed to sustain the flows. (The system is usually intertwined with other systems, but we did not identify all of these linkages in this project.)

Figure 13a shows the concept of a module with material inputs, losses and ou and direct energy inputs. Figure 13b shows that indirect energy is also involved in



(1) Flow is dependent upon type of material and product.
(2) Losses of material occur from all processes, but are not shown in this diagram.

FIGURE 12. GENERALIZED PRODUCT SYSTEM

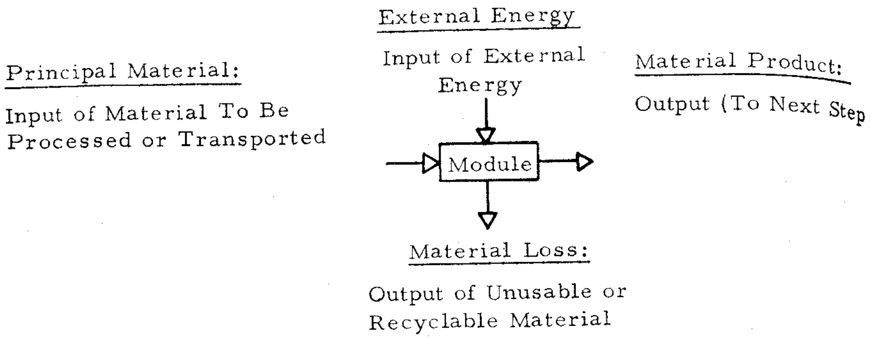


FIGURE 13a. A MODULE IN PRODUCING MATERIALS

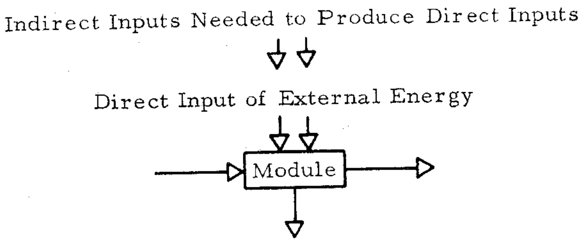


FIGURE 13b. MODULE SHOWING CONCEPT OF DIRECT AND INDIRECT EXTERNAL ENERGY

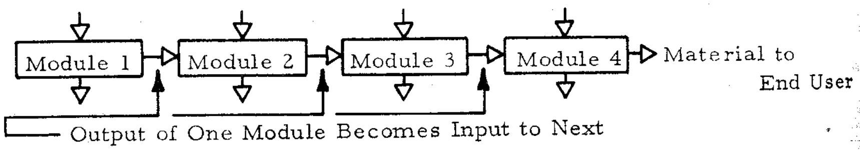
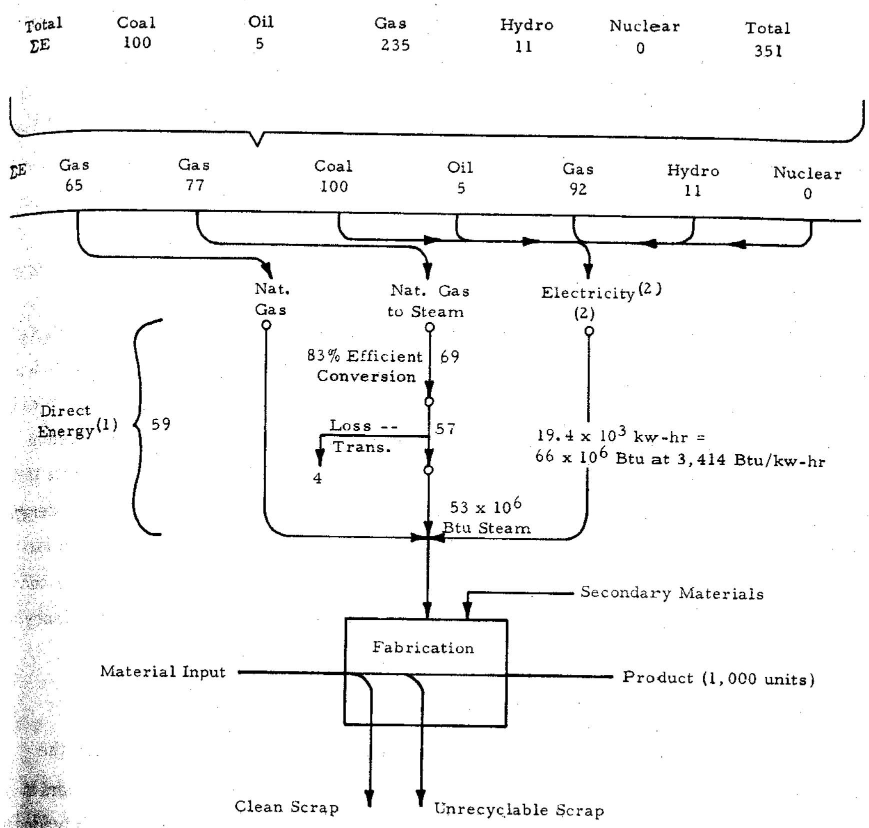


FIGURE 13c. MODULE STRING OR "TRAJECTORY"

FIGURE 13. MATERIALS AND ENERGY FLOWS OF MODULES -- CONCEPT

delivering the direct energy. Figure 13c shows that modules combine in a system to gi flows of material. The total energy for a string of modules is the sum of the direct an indirect energy inputs to all modules in the string or system.

Figure 14 is an example of the actual type of calculations made on a module to show material inputs, losses, and outputs, as well as the direct and indirect energy inputs. It was at this point that we utilized the data from the CERI fossil fuel study--



(1) Direct Production Energy only. Support energy is in another module.
(2) Colorado grid.

ote: All numbers are energy flows in million Btu.

GURE 14. ENERGY AND MATERIAL FLOWS FOR A MODULE

Findings

The purpose of the study was to identify means of producing the energy embodied in the product.

There are a number of ways by which the energy requirements for product systems can be reduced. In considering this matter, one must recall that materials represent sequestered energy of production and, for some materials, fuel value. Further, this sequestered energy is quantified per unit weight of finished product. Some sequestered energy from losses of materials in the production processes is assigned to the finished product. Following are six means of reducing product sequestered energy which were quantified by the study for the industrial client.

(1) NEW OR IMPROVED METHODS OF PRODUCING OR PROCESSING MATERIALS

An example of this would be the wet chemical extraction of aluminum from ores, such as the potential chloride process patented by Alcoa. Improvements of this kind will depend upon science and engineering and on economics. There will be countervailing forces in extractions as higher-grade ores are depleted and more energy must be expended in extracting minerals from lower-grade ores. Increased byproducts and coproducts to which a portion of energy use can be assigned will reduce product sequestered energy. Any process which reduces scrap, or which at least recycles scrap, will result in less sequestered energy. That is to say, efficiency in materials recovery, processing and fabrication which improves the product-to-loss ratio will improve energy efficiency.

(2) ENERGY CONSERVATION IN MATERIALS PRODUCTIONS AND PROCESSING

Many industries and corporations are making rigorous efforts to reduce the amount of energy used in materials productions. This has been going on for years in many companies in the interests of economy. Low energy prices in the past have led to many practices which are inefficient and wasteful as regards energy. The glass, aluminum, steel, plastics, and paper industries are all among the ten major energy-consuming industries in America. For this reason, the Federal government is making special efforts to work with these industries for energy conservation.

Energy quality should be matched to the processing tasks to be performed in a better manner than we have at present.

There are some counterproductive trends in this area, also. For example, glass plants may convert from gas to electricity due to the natural gas depletion problem. Even though the electric furnace is more efficient in terms of direct energy, the inefficiency of coal-electric plants will require more total Btu's of coal the the Btu's of gas for the gas furnace process.

(3) ENERGY PRODUCTION EFFICIENCY AND CONSERVATION

New and improved methods of producing energy will result in lower sequestered energy in materials processing. Some energy-production processes are close to maximum efficiency until new technologies are developed. Thermal electric plant efficiency has risen from 10% in the early part of the century to about 39% in the most modern plants, but the increase in efficiency has tapered off in recent years as limits to efficiency are approached. Advanced power cycles, with gas turbines ahead of the boilers, and "bottoming cycles," with Rankine cycles using low temperature heat which is presently exhausted, may raise efficiencies to 60% in thermal-electric production. Cogeneration may result in additional efficiencies. Refineries are becoming considerably more efficient now that energy conservation is a national goal. Natural gas is seldom flared any more. On the other hand, synthetic fuels, when produced, will be more energy-intensive than natural gas and petroleum.

(4) LIGHTWEIGHTING OF PRODUCTS AND PACKAGING

Obviously, the use of less material for a product will result in a lower sequestered energy of the product. Reductions in materials will be dependent upon technology (new alloys, for instance) and economics. The configuration and structural design of products can reduce the amount of material. Packaging of products represents a significant amount of energy; product characteristics dictate packaging to an extent. Lightweighting of packaging can be important.

(5) RECYCLING OF MATERIALS, SCRAP, PACKAGING, AND FUEL VALUE MATERIALS FOR ENERGY GENERATION

A major objective of this study was to quantify the energy effects of recycling. It should be noted that recycled material can enter the production stream at various points. The farther downstream that reentry occurs, the more savings of energy, in general. Recycling is a very important means of reducing sequestered energy. Refurbishing and reusing a product is highly desirable in general, as the recycle entry point is far downstream in the system.

(6) SHIFTING MATERIALS TO THOSE WITH LESS SEQUESTERED ENERGY

Another major objective to this study was to quantify this matter; we found that there are distinct differences between materials options.

This study could not identify all possible energy-efficiency measures. We have identified only the major measures which appear to be feasible for the next decade. There are many uncertainties. The price of energy is one of the most important factors.

If energy prices continue to increase, industry will make capital investments and operating changes to save money in the purchase of energy. Governmental policies can affect this situation, both in controlling prices and in providing economic incentives for energy conservation. The rate of implementation of technological change (such as new alloys) and institutional change (such as municipal solid waste recovery agencies) is difficult to forecast, also.

CONCLUSION

We feel that net energy analysis and energy analysis of materials flows are valid analytical and management tools. Much more research and demonstration is in order before these tools will find their best and most useful applications. A problem remains in fostering the understanding of energy analysis by potential users.

There is continuing debate amongst net energy analysts on the desirability of developing standard ground rules for net energy analysis. There is some merit in such an approach, especially if Federal agencies intend to utilize net energy analysis in decisions.

We feel that net energy analysis provides a new dimension to information which can be used in decisions and planning. It provides physical data which cannot be gleaned from the scrutiny of economic information.

The user of net energy analysis must be aware of the different qualities and types of energy which are all measured by British thermal units (or some other physical energy measurement unit.) The utility of each type of energy will be different. The same principle applies in using economic units of measurement, of course. For example, a company may have physical and intangible assets, all represented by dollars. Some of these asset dollar values will have been depreciated according to rather arbitrary rules established by accountants and governments. however, the corporate executive will have a different utility function for a dollar representing fixed assets, liquid assets or quick assets. In utility or qualitative terms, dollars vary according to what they represent. This concept applies to physical units of energy as well.

Possible applications of net energy analysis are in engineering studies, technology assessments and comparisons, alternative policies vis-a-vis alternative trajectories and end uses, resource and depletion studies, and resource allocation to meet end use goals.

The main problems with net energy analysis seem to lie, not with net energy analysis itself, but in semantics and decision theory.

SOME THEORETICAL CONSIDERATIONS OF NET ENERGY ANALYSIS

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ABSTRACT

Several methodologies have been developed to perform net energy analysis. However, considerable confusion still surrounds the purpose and definition of the concept. This paper develops a working definition of net energy analysis based on fundamental principles. It is ascertained that the critical element of the approach is the determination of the gain function: the function that describes the relationship between the energy produced by and the energy required for an energy production process. Furthermore, it is determined that the temporal dimension of the gain function is a key item of interest. This results from the two major factors that can impact the gain of an energy production process over time: technological advance and resource depletion. The former is responsible for gain enhancement while the latter contributes to gain deterioration. Evaluation of technological advancement requires a methodology that can account for all the subtle and pervasive "energy subsidies" that contribute to the successful deployment of the technology. Most of the existing methods of net energy analysis attempt to accomplish this task. However, only one methodology, energy circuit analysis, addresses impacts related to the resource depletion component of the gain function. Nonetheless, the method relies on an "energy quality" scale that is itself technology dependent.

The major hypothesis of this paper is that a gain function can be determined independent of technology. Such a function, based on thermodynamic principles, would be utilized to determine the minimum theoretical work necessary to process an energy resource of any particular quality and spatial distribution. Several forms of the gain function are explored to investigate possible modes of dynamic behavior. In addition, ramifications and potential applications are discussed.