APPENDIX G THE APPLICATION OF NET ENERGY ANALYSIS TO SYNTHETIC FUELS

A. THE NET ENERGY ISSUE

Net energy analysis is a label for various methodologies whose objective is to measure the energy inputs and energy outputs of a technological process in an attempt to determine the net energy impact of that technological process. Other labels which have been used in this country and in Europe are "energy accounting," "energy balance analysis," "energy analysis," "gross energy requirements," and—derisively by some critics—the "Btu theory of value."

The discussion here will only deal with net energy analysis as it relates to energy supply technologies, although it can also be applied to energy conservation techniques. As regards energy supply, the net energy issue arises from the reality that "energy must be expended in order to get energy." If the energy expended were more than the energy output, then the process could be viewed as a "net energy sink." So the first concern of net energy analysts is to determine whether a given energy supply process has a "positive energy balance." Going beyond that kind of first order check on the energy efficiency of a process, net energy analysts believe that net energy calculations can be used as an index to compare technical design variants of a given technology, or to make comparisons across different energy supply technologies. This involves the use of net energy calculations as a <u>policy criterion.</u> The controversy over net energy analysis is over whether it is just useful as one index for relatively narrow engineering and scientific comparisons, or whether it can be used as a heavily-weighted criterion in broader comparisons of energy supply options.

At the federal level, several Senators and Representatives have expressed concern that given energy supply modes could use up more energy than they produce. The Federal Nonnuclear Energy Research and Development Act of 1974 includes five governing principles (Section 5a) for the design and execution of ERDA programs, including the following: "The potential for production of net energy by the proposed technology at the stage of commercial application shall be analyzed and considered in evaluating proposals." Although net energy analysis is being taken seriously within government as one useful index among many for evaluating technology variants, there is considerable controversy over whether it should be heavily relied upon to make policy comparisons across energy supply technologies.

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As will be discussed later in this Appendix, net energy analysis is in its methodological infancy, with many existing disagreements over inclusion or exclusion of particular Btu inputs and outputs in the calculations. Perhaps for this reason, net energy analysts have not yet attempted comprehensive comparisons of energy supply technologies, but have focused their attention on three energy supply modes where they think there may be a net energy problem: (1) fission nuclear power, (2) shale oil recovery, and (3) offshore oil drilling. Since this Appendix deals only with synthetic fuels, the net energy aspects of shale oil recovery will be the focus. The methodological issues of net energy analysis will be illustrated by using Btu inputs and outputs for oil shale recovery. Although synthetic fuel technologies other than shale oil recovery have not been seriously challenged on a net energy basis, some preliminary net energy calculations will be presented for them.

B. APPLICATION OF NET ENERGY ANALYSIS TO OIL SHALE RECOVERY

The applicability of net energy concepts to oil shale development became a public issue when the following paragraph appeared in a June 8, 1974 Business Week article entitled "The New Math for Figuring Energy Costs":

> Recently, Texaco, Inc., decided to forego bidding on oil shale leases in Colorado. "The figures just didn't work out," explains one executive. "It was hard not to make a bid, but we couldn't justify it." Texaco figures that shale oil will not pay off. After developing the necessary technology, buying massive new machinery, moving tons of earth, reclaiming acres of land, and processing the shale oil for market, the Btus produced would barely make up for the Btus consumed. Though the company did not phrase it quite that way, Texaco's conclusion is that shale oil recovery is an energy standoff.

This paragraph became quoted in many other press articles and oil shale gained a reputation as a "net energy loser" in many people's minds. The following Texaco denial appeared in the June 22, 1974 issue of Business Week:

> The reference to Texaco in "The new math for figuring energy costs" (Energy, June 8) could be misleading. Texaco's evaluation of last winter's shale leases took a large variety of factors into consideration, and the decision reached should not be interpreted as an opinion that "shale oil will not pay off." Our conclusion simply was that for that particular lease sale, in our particular circumstance, for a wide-ranging variety of reasons, a bid was not indicated.
>
> Texaco remains interested in shale, owns sizable amounts of shale land in the Western U.S., and is participating in the Paraho Development Corp.'s oil shale demonstration project.
>
> James F. Calvert
>
> Texaco, Inc.
> New York, N. Y.

The denial did not receive the same press attention as the initial Business Week article, and so substantial public confusion has remained.

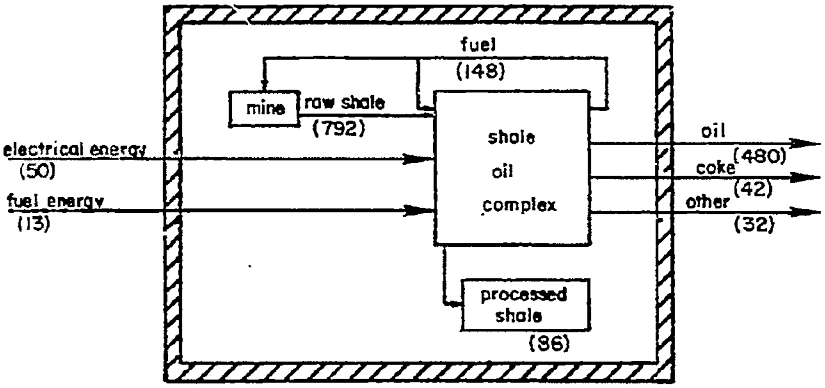

Fig. G-1 ARCO's hypothetical 10^5 bbl/sd shale-oil plant with an "external consumption boundary", showing energy flows in 10^9 Btu/sd; reproduced from a report by C. E. Clark, Jr., and D. C. Varisco of ARCO.

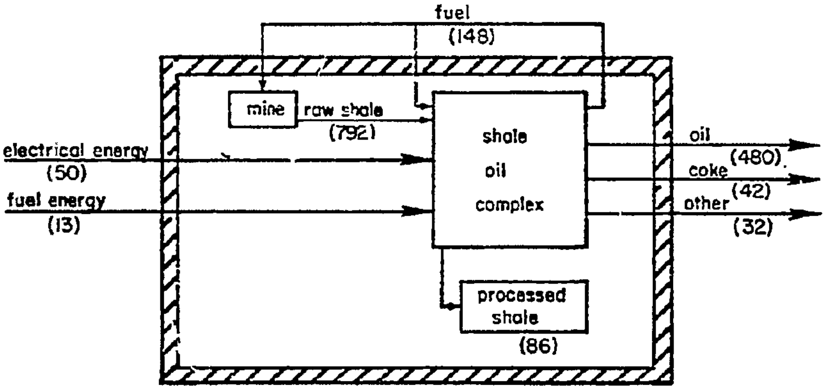

Fig. G-2 ARCO's hypothetical 10^5 bbl/sd shale-oil plant with a "total consumption boundary", showing energy flows in 10^9 Btu/sd; reproduced from a report by C. E. Clark, Jr., and D. C. Varisco of ARCO.

At the time of the Business Week article, there had not been any systematic studies of the net energy contribution of shale oil recovery. In order to try to resolve some of the controversy, the National Science Foundation and the University of California at San Diego (UCSD) sponsored a Workshop on "Net Energy in Shale Oil Recovery" at La Jolla, California. The report of that workshop has been prepared by Professor Sol. S. Penner, Director of the UCSD Energy Center.

One approach taken was to utilize Btu input and output numbers developed by industry for one type of shale oil recovery (room and pillar mining and surface processing) in order to illustrate alternative net energy concepts. What follows is a description of three different net energy ratios:

> Depending on the application involved, there are at least three different classes of definitions for "net energy ratios" or, more simply, "net energy" that may profitably be used. Furthermore, the detailed numbers entering into the definitions have such latitude that the resulting range of values for the net energy may lie anywhere between zero and infinity. We shall now define three net energy ratios, namely, the net energies R_1, R_2, and R_3, and shall then comment briefly on the context in which the numerical values may be advantageously employed as a guide in oil-shale development.
>
> C. E. Clark, Jr., and D. C. Varisco of ARCO have examined a commercial prototype plant producing 10^5 bbl/sd of refined shale oil. The energy flows for this plant (in 10^9 Btu/sd) are shown in Figures G-1 and G-2 with "external consumption" and "total consumption boundaries", respectively.
>
> i. Definitions of R_1
>
> The flow chart with the external consumption boundary (see Figure G-1) is supposed to indicate a process absorbing only energies from external sources and not from the shale-oil recovery process itself. For this shale-oil recovery scheme, it is convenient to define the net energy
>
> $$R_1 = \frac{\text{total energy out (as oil, coke, other fuel)}}{\text{external energy in (as fossil fuel energy required to produce electrical energy and as fossil fuel directly)}}$$

The ratio R_1 is evidently a useful parameter when the normal resource value prior to energy recovery is considered to be zero. In this case, the only operative consideration is the extent to which resource processing provides increased energy "externally". In order to reduce energies to substantially equivalent form, it is customary to convert the required electrical energy into equivalent fuel (thermal) energy by dividing the electrical energy by about 0.33, which represents the approximate value of the fraction of fossil-fuel energy that is converted to electricity in a conventional generating station. It should be noted that, in the definition given for R_1, internal energy consumption (as represented by the fuel energy flow of 148 x 10^9 Btu/sd) is not <u>explicitly</u> considered in the defining relation although the magnitude of this flow clearly affects the net outflow of energy. We note that R_1 can, in principle, be made arbitrarily large by using product fuel energy within the process enclosure to produce all of the electrical- and fuel-energy requirements. Needless to say, this scheme (which yields $R_1 \rightarrow \infty$) is not generally economically advantageous. The extent to which energy requirements are profitably generated internally is both site-specific and company-specific. Thus, there is a set of values R_1 subject to such constraints as location of the site, availability of electrical energy at advantageous prices, preferred distribution systems for the operating company, etc. These factors will determine the preferred value (on economic grounds) of the net energy ratio $R_{1,i,j}$ for the ith industrial concern engaged in shale-oil recovery at the jth site. Thus, for the ith company, the development of its jth site will be heavily influenced by the applicable value of $R_{1,i,j}$ and, <u>in a free market</u>, the larger $R_{1,i,j}$ is, the lower and more competitive will the final product cost be for the ith concern operating at its jth site. Society at large will generally support this methodology for determining site-development strategy provided the decision has been made that the particular program for resource recovery is in the public interest.

ii. Definitions of R_2

The definition of R_2 follows from the diagram with total consumption boundary shown in Figure G-2 , viz.

$$R_2 = \frac{\text{total energy out (as oil, coke, other fuel)}}{\text{external energy in + fuel-energy derived from shale oil used in processing}}$$

The preceding definition is again company- and site-specific and thus represents a set of values $R_{2,i,j}$ for the optimized recovery development performed at its jth site by the ith company.

If we regard the total available resource as a national asset and introduce the hypothesis that partial recovery of the resource is permissible on the grounds that future technological developments will ultimately allow complete resource recovery, then the maximum value of $R_{2,i,j}$ attains a special significance in absolute terms in the sense that resource development is in the public interest for the largest possible value of $R_{2,i,j}$.

iii. Definitions of R_3

We may argue that the national interest requires complete resource development at every site and that any fuel not immediately recovered by an optimized process is effectively lost because secondary shale-oil recovery will be so costly that the unrecovered energy is effectively lost to society. The definition of R_3 is then

$$R_3 = \frac{\text{total energy out (as oil, coke, other fuel)}}{\text{external energy in + internal energy used as processing fuel + internal energy not recovered by the primary recovery process}}$$

The ratios R_3 are again company- and site-specific. They will almost always be less than unity (e.g., because of retorting losses in situ processing or because of mining loses in room-and-pillar underground mining).

Using the Btu values shown in Figures G-1 and G-2 one obtains a value of 8.8 for $R_{1,i,j}$ and a value of 2.6 for $R_{2,i,j}$. The use of $R_{3,i,j}$ is ruled out the basis that the shale which remains after mining can be recovered someday with secondary recovery techniques, and therefore that shale should not be considered "lost." (The value of $R_{3,i,j}$ if it had been calculated with the above numbers, would be 0.75.)

It is evident that the issue of whether this oil shale technology is a "net energy sink" depends on whether $R_{3,i,j}$ makes sense. There is a somewhat different justification than the one offered by Penner for not counting the unmined shale as an energy resource cost. In order for energy resources to be costly in energy, they must have some valuable alternative energy use which is being sacrificed. Does the oil shale which remains after room and pillar mining have a valuable alternative energy use? Only if there is some better mining technique available. So, even taking Btu analysis on its own terms, it is difficult to see how the remaining shale can be viewed as a Btu energy cost.

Based on the Btu input and output numbers from ARCO, the above oil shale recovery technology could not be considered even close to being a "net energy sink." That conclusion does not preclude the use of net energy analysis for making other comparisons, such as between alternative shale oil recovery technologies.

C. OTHER METHODOLOGICAL ISSUES

Net energy analysis is in the newborn infant stage of methodological development. It is premature to reach definite conclusions as to (1) whether it will ever reach higher levels of methodological refinement or, (2) how broad its application will be to energy policy decisionmaking. It is appropriate, however, to examine some of the methodological issues of net energy analysis in relation to the most frequently employed competing methodology, benefit-cost analysis.

To the extent that benefit-cost analysis slavishly uses prevailing prices, then it can reach erroneous conclusions which may not be reached using net energy analysis. The most often-cited example is price-regulated natural gas. If the regulated price is used, then a benefit-cost analysis might conclude that it is "economic" to pump a given number of Btu's into an oil deposit in order to recover some lesser amount of Btu's of oil. Net energy analysis would obviously conclude that such a use of natural gas involves a net energy loss. A proper benefit-cost analysis performed to maximize national efficiency rather than an individual corporation's profits would also recommend against such use of natural gas. In the calculations for a national benefit-cost analysis a higher "shadow price" of natural gas would have to be used which reflected the societal value of the gas rather than its prevailaing price. Interestingly, one of the approaches for estimating the correct shadow price for a thousand cubic feet of natural gas is to measure the sale prices of equivalent amounts of Btu's of other fuels which compete directly with natural gas in terms of energy use and location. Thus, Btu calculations can be a very useful complement to benefit-cost analysis when sale prices have to be corrected for regulatory distortions.

A basic difference between benefit-cost analysis and net energy analysis is that dollars are used as the common unit of measure, or "numeraire," in one case and Btu's are used in another. It is clear to most people, including most energy analysts, that all Btu's are not of equivalent value in an energy system. If they were, no petroleum would ever be converted to electricity, since about two-thirds of the petroleum Btu's are lost in the process. Another example of Btu inequality is a technology which is economically valuable even though it is a net energy sink—the pumped storage of water for later generation of hydroelectric power during peak electricity-consumption periods. The Btu's of peak electricity are obviously worth a lot more because of their time-specific value than the Btu's used to pump the water into storage. One approach is to weight Btu outputs by "quality indexes" in order for net energy analysis to be credible. The methodology which would be used for such weighting is in the very early stages of conceptual development.

Benefit-cost analysis and net energy analysis are even further apart on the valuation of energy resource inputs. Benefit-cost analysis relies upon economic valuations of the "relative scarcities" of energy resources. These economic valuations are, in turn, derived from "present capitalized value" calculations which relate the present value of a resource in the ground to its stream of expected future use. Discount rates are used by both the private sector and the public sector in these kinds of calculations. While there may be much debate over what numerical discount rate should be used by the private sector or the public sector in a given instance, there is agreement that a dollar of real resource cost today should be valued higher than a dollar of real resource cost sometime in the future. Time preference for resources is the core of resource economics, as practiced by either the public or private sector.[1]

As practiced so far, net energy analysis has not applied discount rates to Btu's. It is too early to say that they will not be used or that a conceptual framework can't be developed to specify what kind of discount rate would apply. That is a challenge for net energy analysts. All that is intended here is to point up the importance of the issue for resource valuations. Take, for example, the unmined shale which was so important in the discussion of $R_{3,i,j}$ in the previous section. The net energy analyst has the stark options of either including or excluding those Btu's entirely. The benefit-cost analyst, on the other hand, can consider the value of that shale for future recovery but value it close to zero because the application of the discount rate makes long-run recovery by new mining technology a low value activity in present value dollars. The capital theory implications of net energy analysis have to be dealt with before it can achieve wide application to policy analysis.

Another methodological issue of net energy analysis is how to measure all the "indirect" Btu's embodied in the material and equipment inputs to an energy supply system. This problem does not arise in benefit-cost analysis since market prices are reasonably good measures of both direct and indirect inputs. Various methods can be employed, including input-output analysis, various engineering rules-of-thumb, and various dollar/Btu conversion ratios. One of the problems involved in these calculations is what fuel mix to assume was used in the production of a physical input. If X cubic yards of concrete are listed as an input, is one to assume the concrete was manufactured using heat from oil, natural gas, or coal? Even where the amounts of Btu's involved is not crucial to the analysis, the messiness of these kinds of calculations can be frustrating to the analyst.

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[1] See Orris C. Herfindahl and Allen V. Kneese, Economic Theory of Natural Resources (Charles E. Merrill Pub. Co.: Colum us, Ohio, 1974); and Harold J. Barnett and Chandler Morse, Scarcity and Growth: The Economics of Natural Resource Availability (Johns Hopkins Press: Baltimore, Md. 1963).

Still another issue is whether net energy analysis is superior to benefit-cost analyses in terms of accurately measuring and incorporating into the analysis various kinds of environmental impacts. This question can't easily be dealt with by a priori reasoning, so clarification of the issue must await much further research on ecosystem impacts. However, it should be noted that the Synthetic Fuels Commercialization Cost-Benefit Analyses has attempted to incorporate not only encironmental costs of compliance but also externalities and socio-economic impacts into the analysis. This is a step forward and should assist in an informed policy decision with public debate then focused on the environmental concerns and their costs.

D. PRELIMINARY COMPARISON OF SYNTHETIC FUEL SUPPLY SYSTEMS USING NET ENERGY CALCULATIONS AND ENERGY EFFICIENCY CALCULATIONS

The resource and processing energies of various synthetic fuel processes and resulting net energy ratios and process efficiencies are shown in Tables G-1 and G-2. All values are given in units of 10^{12} Btu per year; those for resources and products were calculated directly from process flow data, but values for capital goods and operations were indirectly determined. Using published construction cost data for the various mining and processing facilities[1/], a capital goods-to-energy conversion factor of 50,000 Btu per dollar was applied to produce equivalent energy inputs.[2/] Using operation and maintenance data for the same nominal facilities[3/], costs of non-fuel materials and manpower were similarly converted to Btu values at 50,000 Btu/dollar. However, fuel and electricity consumed in operations were counted at their effective heat values (10,000 Btu/Kwh for electricity).

For each alternative fuel, process steps including resource extraction, feedstock preparation and conversion to final product were evaluated and combined to give an overall 'fossil resource to final product' process. All processes were scaled to equivalent final output levels in order to facilitate direct comparison of individual data.

For Net Energy Analysis, only the 'external consumption' net energy ratio (R_1) could be calculated from the facility data used since no estimates of internally manufactured fuels consumed in the various processes were available. New data on synthetic fuel recycle in these processes would allow the calculation of R_2. The values of R_1 shown in the table are also somewhat increased by the absence of product delivery energies in the denominator. The values of R_1 shown thus represent the external consumption net energy ratios for products at the plant outlet.

[1/] Paths to Self-Sufficiency; Directions and Constraints" Final Report, Phase 1, August 1974; Bechtel Corporation, San Francisco, California. Report on Contract NSF-C-867

[2/] The 50,000 Btu/dollar conversion was developed as a weighted average of energy conversion factors used in the Oregon Governor's Office's "Energy Study" - Interim Report, July 1974.

[3/] "Manpower, Materials, Equipment and Utilities Required to Operate and Maintain Energy Facilities", March 1975 report of Stanford Research Institute to Bechtel Corporation in support of Contract NSF-C-867; Menlo Park, California

Table G-1
RESOURCE & PROCESSING ENERGIES OF SYNFUELS PROCESSES
(In 10^{12} Btu/Year)

		A	B	C	D	E	F	G	H
	Equivalent Barrels Per Day at 6×10^6 BTU/Bbl.	Resource Base Reduction	Resource Extracted	Intermediate Feed Stock	Primary Product	Other Products	Intermediate Process Energy	Final Process Energy	Total External Energy
High-BTU Gasification	50,000								
Western Coal - Surface Mined		204	198	180	110	0	.79	2.2	3.0
Eastern Coal - Deep Mined -room & pillar (longwall)		360(270)	216	180	110	0	1.1	2.4	3.5
Shale Oil Recovery	50,000								
Surface Retorting - room & pillar (longwall)		215(166)	133	-	110	0	-	7.2	7.2
In-Situ Retorting (*rubbleized)		310	*215	-	110	0	-	6.9	6.9
Methanol Production	50,000								
Western Coal - Surface		196	190	173	110	0	.80	2.4	3.2
Eastern Coal - Deep (longwall)		347(260)	208	173	110	0	1.1	2.7	3.8
Syncrude Production	50,000								
Western Coal - Surface		179	174	158	110	0	.77	9.2	10.0
Eastern Coal - Deep (longwall)		316(236)	189	158	110	0	1.1	8.6	9.7
Solvent Refined Coal	25,000								
Western Coal - Surface		98	96	87	55	11	.51	3.8	4.3
Eastern Coal - Deep (longwall)		174(130)	104	87	55	11	.71	3.5	4.2
Low-BTU Gasification	25,000								
Western Coal - Surface		93	90	82	55	0	.50	2.8	3.3
Eastern Coal - Deep (longwall)		164(122)	98	82	55	0	.67	3.1	3.7
Waste/Coal Utility Fuel	25,000								
Western Coal - Surface		57	5	49.4	55	0	-	.34	1.1
Eastern Coal - Deep (longwall)		100(75)	60	49.4	55	0	-	.48	1.2
Waste (paper removed)		2,000 T/D @ 6,000 BTU/#lb →		5.6		Metals	-	.76	

Table G-2

Net Energy Ratio R_1 & Process Efficiencies of Synfuels Processes

High BTu Gasification	I. Net Production (D+E -H)	J. Perfect Recovery Efficiency(%)	K. Actual Process Efficiency (%)	R_1 Net Energy Ratio (External Consumption)
Western Coal	107.0	54	52	36.7
Eastern Coal (longwall)	106.5	49	30(39)	31.4
Shale Oil Recovery				
Surface Retorting (longwall)	102.8	77	48(62)	15.3
In-Situ Retorting	103.1	48	33	15.9
Methanol Production				
Western Coal	106.8	56	55	34.4
Eastern Coal (longwall)	106.3	91	31(41)	29.7
Syncrude Production				
Western Coal	100.0	57	56	11.0
Eastern Coal (longwall)	100.3	53	32(42)	11.3
Solvent Refined Coal				
Western Coal	61.7	64	63	15.3
Eastern Coal (longwall)	61.8	59	36(48)	15.7
Low-BTu Gasification				
Western Coal	51.7	57	56	16.7
Eastern Coal (longwall)	51.3	52	31(41)	14.9
Waste/Coal Utility Fuel				
Western Coal	53.9	99*	95	50.0
Eastern Coal (longwall)	53.8	90*	54(72)	45.8

* [Waste resource value assumed zero.]

The R_1 values for shale oil recovery shown in Table G-2 differ from those given earlier in this paper, since the external inputs included product delivery energies and the data on all external inputs were more extensive. However, the data inputs and methodology used here for oil shale processes are consistent with those used for the other alternative fuels, so that the relative values of R_1 are directly comparable.

For purposes of comparison, various process efficiencies were also calculated for each alternative synthetic fuel, and are shown in Table 2. These include: the process efficiency from extracted resource to final synthetic fuel (j), is equal to the maximum overall efficiency if resource extraction were perfect (100% recovery). Present mining techniques provide only in complete recovery, thus the actual overall process efficiency from resource in place to final synthetic fuel (k) is one indication of the capabilities of existing technology. Table 3 shows how the various synthetic fuels technologies compare with one another when ranked according to: (1) the net energy ratio R_1, and (2) actual energy efficiencies of the processes. Since the net energy ratio R_1 does not account for the Btu's in the fossil resource consumed, whereas the process efficiencies do, the rankings by the two indexes are different. Table 3 illustrates the point that there are other types of Btu analysis than just net energy analysis. If one is more concerned about the amount of the externally supplied Btu's used up in synthetic fuel processes, then one might consider the net energy ratio R_1 more useful. On the other hand, if one is more concerned about the problems of fossil fuel extraction, and the amount of heat and other pollutants released to the biosphere during conversion, then process efficiencies might be considered a more useful index.

Finally, the preliminary nature of the numbers in Tables G-1, G-2 and G-3 should be reemphasized. Since the capital costs, operating and maintenance data used to develop the external Btu inputs are accurate only within ± 20%, and the individual process efficiencies are likewise only best estimates, the calculated values of R_1 may err as much as ± 30%. While the R_1 rankings in Table 3 should be considered tentative, the ranking based upon process efficiencies, is somewhat more reliable.

Table G-3

Ranking of Synfuels Processes by Net Energy Ratio (R_1) and Process Efficiency

Ranking by net energy ratio R_1		Ranking by process efficiency
2	High-BTu Gasification	4_1 *
4_2 *	Shale Oil Recovery	4_2 *
3	Methanol Production	3_3 *
5	Synerude Production	3_1 *
4_3 *	Solvent-Refined Coal	2
4_1 *	Low-BTu Gasification	3_2 *
1	Coal/Waste Utility Fuel	1

* (virtual tie)

E. CONCLUSION

Net energy analysis is one among many techniques which can be used for evaluating synthetic fuel technologies. The methodology of net energy analysis is at an early stage of development, and may undergo substantial future changes and refinements. Using currently available methodology and data, all the synthetic fuel technologies under consideration in the Synthetic Fuels Commercialization Program would make a significantly positive net contribution to U.S. energy supply.