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SYSTEMS, SCIENCE AND SOFTWARE

SSS-R-77-3020
Revision 0

AN ENERGY STUDY OF PIPELINE TRANSPORTATION SYSTEMS

Executive Summary

by

William F. Banks

FINAL REPORT
Contract EY-76-C-03-1171

DEPARTMENT OF ENERGY
SAN FRANCISCO OPERATIONS OFFICE
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MASTER

31 December 1977

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1.0 OBJECTIVES

The work reported here is a part of a project which was conducted by the team of Systems, Science and Software (S^3) of San Diego, and Pipe Line Technologists, Inc. (Pipetech) of Houston, under DoE contract EY-76-C-03-1171, "Energy Study of Pipeline Transportation Systems." The basic objectives of the study are the following:

1 - To characterize the pipeline industry and understand its energy consumption, i.e., the patterns of consumption and the quantities and intensities of that consumption in each of the five major pipeline industry segments: gas, oil, slurry, fresh water and waste water.

2 - To identify opportunities for energy conservation in the pipeline industry, and to recommend the necessary programs of research, development, and demonstration (R,D,&D) to exploit those opportunities.

3 - To characterize and understand the influence of the federal government on the introduction of energy-conservative innovations into the pipeline industry.

4 - To assess the future potential of the pipeline industry for growth and for contribution to the national goal of energy conservation.

This project final report is an executive summary presenting the results from the seven task reports listed in Table 1.1-1.

TABLE 1.1-1

Project Reports

SSS-R-77-	Title	Associated Task
3020	An Energy Study of Pipeline Transportation Systems - Executive Summary	All
3021	An Ecomomic Model of Pipeline Transportation Systems	1 (partial)
3022	Energy Consumption in the Pipeline Industry	1
3023	Slurry Pipelines - Economic and Political Issues - A Review	2.1
3024	Federal Regulation of the Pipeline Industry	2.2
3025	Efficiency Improvements in Pipeline Transportation Systems	3
3027	The Prospects for Energy Conservation in the Pipeline Industry	4 and 5
3069	S^3 Financial Projection Model - Preliminary User's Manual and System Overview	1 (partial)

2.0 ENERGY CONSUMPTION IN THE PIPELINE INDUSTRY

In the introductory section of this report, the first major objective of this study was identified as understanding the energy consumption in the pipeline industries. Stated equivalently, it is desired to understand the magnitude of the energy being expended, its pattern, how it could be reduced, and what R,D,&D program will best enable and/or enhance such reduction. The purpose of this section is to summarize the answers to the first of these questions, i.e., how much energy is being expended by the industry and what its intensity is. Before proceeding with the summary of these results, energy intensity will be defined.

As used here, the term "energy intensity," or EI, is the energy consumed per unit of transport accomplished. This index of merit is often called energy intensiveness (EI), but for succinctness is referred to here as energy intensity. It is calculated from any of the formulas:

$$I_E = \frac{E}{QxD} = \frac{P}{FxD} = \frac{\frac{dE}{dt}}{\frac{dQ}{dt}xD}$$

where

$I_E \triangleq$ energy intensity

$E \triangleq$ energy consumed

$Q \triangleq$ quantity of commodity transported

$D \triangleq$ distance transported

$P \triangleq$ power

$F \triangleq$ commodity flow.

The second and third formulas yield an instantaneous value for I_E, while the first yields an average over whatever time period E and Q have been integrated. In this study, only annual averages are considered, so the line is considered to be in quasi-steady state operation. It is, of course, recognized that system transients do adversely affect energy consumption (see Sect. 4.3.6.1.2, Report 3025 of this series) in connection with pipeline duty cycles.

The task of developing an accurate and precise estimate of energy intensity reduces in practice to an effort to determine the three quantities E, Q, and D, or equivalently, the numerator E and the denominator (QxD). As will be seen, in the case of gas pipelines the numerator E is known rather accurately but the denominator (WxD) can be determined accurately only by research into the records of each individual piepline company. The opposite situation obtains with the oil pipelines, where the denominator (QxD) is reported by each company and published by the ICC, but the numerator E can only be determined accurately by research into the records of each individual pipeline company.

The energy intensity can be expressed as a dimensionless ratio of friction energy dissipated to useful work performed. However, for purposes of drawing comparisons with other transportation modes, it is desirable to convert the I_E to the commonly used set of units, which in the ancient English system is

$$\frac{\text{Btu}}{\text{ton-mile}} .$$

This conversion introduces an inaccuracy, since the densities are not reported, and thus the analyst must guess at the conversion factors. Table 2.0-1 presents the summary of the energy estimates for the six types of pipeline which were examined. The following sections discuss these figures briefly. For further detail, the reader is referred to Report R-3022 (see Table 1.1-1).

Table 2.0-1

PIPELINE ENERGY ESTIMATES

	Natural Gas	Crude Oil	Petroleum Products	Coal-Water Slurry	Water Supply	Waste Water	Total
Energy Consumption (Quads)	0.710	0.070	0.068	0.0044	0.050	0.017	0.92
Energy Intensity	2000[1]	300[1]	400[1]	4000[1]	220[2]		

[1] Btu/ton-mile

[2] Kw-min/10^5 gal-ft

2.1 Gas Pipeline Energy Summary

The total annual energy consumption of the gas pipeline industry, as pipeline fuel, is approximately 0.7 Quad (7×10^{14} Btu/hr). The peak consumption, which occurred in 1972, was 766,156 x 10^{6} cf, or approximately 0.8 Quad. In addition, a small amount of compression energy, estimated to be less than 5%, is taken from non-gas sources, principally as purchased electricity.

It is estimated that between 85 and 90% of the pipeline fuel is consumed in the transmission function. The production function consumes 4 or 5%, and the collection function consumes between 6 and 8%, while the storage function appears to consume a negligible amount. No reliable data have been found to indicate consumption by the distribution function, but it is believed to be of the same order of magnitude as the collection function, less than 8%. The energy intensity (EI) of gas pipelines varies widely, usually between about 1000 and 4000 Btu/ton-mile. The average appears to lie near 2000.

The pipeline companies do not calculate their energy intensity, since it is not a useful parameter to them, although energy consumption and conservation are matters of primary concern to all levels of their management. However, one large gas pipeline company, to cooperate with the DoE, performed the necessary research to assemble the data and calculate the EI of their entire trunkline system for 1976. The result was just over 1000 Btu/ton-mile. In earlier years, when the system throughput was higher, the EI was possibly as much as 50% higher.

The minimum-cost EI appears to occur near the lower end of the 1000-4000 range. Of further interest is the fact that the maximum profit and cash flow appear to occur near the top of the range. Therefore it appears that the price of gas must increase by several times above the present interstate-regulated value of $1.48/Mcf before the pipeline owner will be motivated to operate at the most energy-conservative condition. In making this observation, it is recognized that there are a great many other practicalities that militate against operating gas pipelines in their most energy-conservative mode.

2.2 Crude Oil Pipeline Energy Summary

The 1976 energy consumption of the United States crude oil pipeline industry is estimated to be 2×10^{10} kw-hr (0.07 Quad). Within the inherent accuracy of the method which was employed to derive this figure, it would carry a high confidence level. There are, however, unknowns regarding the input data which render the estimate suspect. Further research would be required to resolve these unknowns and improve the accuracy of both the method and the specific results.

The estimate for the energy intensity of the crude lines is 286 Btu/ton-mile, which is much below others, e.g., Hirst [1973] and Project Independence [1974]. However, a search of those references has not revealed the basis for the higher numbers, so that reconciliation is not complete, although it will be continued. To avoid leaving impressions of nonexistent accuracy, it is suggested that the rounded value of 300 Btu/ton-mile be used.

2.3 Products Pipeline Energy Summary

Estimates for products lines are 0.068 Quad for the energy consumption and 388 Btu/ton-mile for the energy intensity. The general comments made earlier regarding the crude oil estimates apply here also. It is suggested that the rounded value of 400 Btu/ton-mile be used for the EI.

2.4 Coal-Water Slurry Pipeline Energy Summary

This industry presently consists of only one system, The Black Mesa Pipeline, Inc. The estimate for its total energy consumption, when the complete deslurrification process is taken into account, is 0.0044 Quad. The components of this estimate are shown in Table 2.4-1. The estimate for energy intensity is 3900 Btu/ton-mile, rounded to 4000.

Several comments are in order. First, although the basis for the figure of 341,000 Btu/ton-mile for the pipeline operation is known to be accurate, since it was supplied as a courtesy by Black Mesa Pipeline, Inc., it includes whatever inaccuracy is introduced by the postulated 22% efficiency of the electric generation and distribution grid. Also, the 155,000 Btu for other pipeline operation may be either over- or understated, depending on viewpoint, if the purpose is comparison with other transportation modes. On one hand, most of the energy of slurry preparation is for grinding. Since the coal must be pulverized in any case, it is not fair to charge all of this to transportation. On the other hand, the line falls 2600 ft between its head and its critical elevation. This free gravitational energy compares with about 8000 ft of head which is added by the pumps. Thus, when a comparison is made for equilevel terminals, taking both of these factors into account, the energy consumed in pipeline operation is slightly less (see column 1 of Table 2.4-2).

Second, if one accepts the estimate of Zandi [1974] of 544 Btu/ton-mile for the energy intensity of a railroad to move the coal between the same two points, one sees an apparent large advantage for the railroad. When the effects of distance, scale, and current technology are taken into account, an energy intensity of about 600 Btu/ton-mile is anticipated by pipeline promoters for a 1000-mile, 25 million-ton/year pipeline. The comparison between this estimate and the estimate for the Black Mesa line is presented in Table 2.4-2. For a discussion of the credibility of the former, the reader is referred to Report R-3023 of this series, Section 4.2.2.

Finally, a major conclusion that was reached in this program regarding the future of coal-slurry pipelines is confirmed.

TABLE 2.4-1

Energy consumption - Black Mesa Pipeline
(Btu/ton of coal)

Slurry water supply		36,000
Pipeline operation		
Pumping energy	186,000	
Slurry preparation & other operations	155,000	
		341,000
Deslurrification		
Initial separation	205,000	
Moisture correction, 32 to 10.74%	483,000	
		688,000
	Total	1,065,000

TABLE 2.4-2

Comparison of adjusted energy consumption
(Btu/ton of coal)

		Black Mesa 273 mi 10.74% moisture $4x10^6$ tons 1967 technology		ETSI 1000 mi 2.6% moisture $25x10^6$ tons 1977 technology
Slurry water supply		36,000		25,000
Pipeline operation				
Pumping energy	250,000		351,000	
Other operations	31,000		47,000	
		281,000		398,000
Deslurrification				
Initial separat'n	205,000		65,000	
Moisture correction	483,000		136,000	
		688,000		201,000
Total		1,005,000		624,000
Length of pipeline (mi)		273		1,000
Energy intensity (Btu/ton-mi)		3681		624

The conclusion, discussed in Section 3.3 below, emerges that the coal slurry pipeline is a cost-effective and energy-effective mode of transport, but not in the coal-water form. The coal-methanol slurry offers promise of eliminating the huge energy penalties in the deslurrification process, reducing the total pipeline water requirement by a factor of 3 or 4, and at the same time making a premium engine fuel available.

Since the coal can be separated from the methanol, the methanol can then be sold in the open market. It is then only necessary to charge the transportation process with any excess of energy required in coal conversion to methanol over that required to manufacture methanol by current industrial methods. When that is done, the methanol slurry is much more energy-efficient than either water slurry pipelines or railroads.

The use of oil instead of methanol may be attractive in a few scattered cases. Since the coal cannot be separated from the methanol with any existing, or even contemplated, technology, the energy lost in conversion of the coal to oil must be charged to the transportation process, which renders the oil slurry the least energy-efficient of the three, except in those few markets wherein the coal-oil slurry can be burned directly in the power plant.

Uninhibited enthusiasm for the coal-methanol system is premature under the present absence of an overall system analysis. It is strongly recommended that such analysis be performed.

2.5 Water Systems Energy Summary

The estimate for energy consumption in water supply systems is 0.05 Quad, and for waste water systems, it is 0.017 Quad. Energy intensity cannot be calculated for water systems in the same way as is done for the other pipelines and other transportation modes, because in water distribution systems, unlike petroleum pipelines, the fluid is not pumped through from source to destination. Instead, the water is pumped to a high-level storage tank from which it flows by gravity through the distribution lines to consumers. Since all the energy is input to the system as work to raise the water to the storage reservoirs, the energy intensity for water systems is defined as energy per unit of mass per unit of lift. Thus, an energy intensity that would put these systems on a comparative base with other modes is not definable.

3.0 OPPORTUNITIES FOR EFFICIENCY IMPROVEMENTS IN PIPELINE OPERATIONS

Most of the energy conservation opportunities identified here possess two highly important attributes:

1 - Potential energy savings are large, of the order of several hundredths of a quad.

2 - The technology whereby the energy savings may be realized is broadly applicable outside the pipeline industry.

An example of 1 will be found in Sections 3.1 and 3.2 where it is seen that bottoming engines and internal cooling of IC engines may easily aspire, through ultimate industrywide application, to savings well over 1/10th of a Quad.

An example of 2 will be found in Section 3.5 where the somewhat startling, through still tentative, conclusion is derived that the pipeline application is likely to be a much more attractive breeding ground for fuel cell development than the one on which virtually all of the money is currently being spent, that is, the electric utility application. Rather than a suggestion of misdirection of R&D, this observation merely reflects the fact that, for various reasons, the utility industry and its equipment suppliers have been energetic in persuading the government to support their R&D, while the pipeline industry has chosen to go its own way. It is the identification of just such opportunities as this which is the basic purpose of the present study.

Table 3.0-1 presents the nine programs recommended for pursuit. This study has concluded that each of the listed programs satisfies the first three of the criteria listed below:

1 - Energy-effective

2 - Cost-effective

3 - Technically feasible on a moderate (3-7 yr) time scale

4 - Broadly applicable outside the pipeline industry.

TABLE 3.0-1

Recommended research, development and demonstration programs

1. Gas-fired combined cycle compressor station
2. Internally-cooled internal combustion engine
3. Methanol-coal slurry pipeline
4. Methanol-coal slurry-fired and coal-fired engines
5. Indirect-fired coal burning combined cycle pump station
6. Fuel cell pump station
7. Drag-reducing additives in liquid pipelines
8. Internal coatings in pipelines
9. Pneumatic capsule pipelines

Of the nine recommended programs, the first six on Table 3.0-1 additionally satisfy criterion 4. That is, only programs 7, 8 and 9 are pipeline-peculiar. In each case, of course, the program should be coordinated with other active and planned DoE programs and with other government agencies previously and/or currently engaged in similar or related programs.

The recommended programs in Table 3.0-1 were selected from the field of candidate categories which are listed in Table 3.0-2. With few exceptions, the numbered improvements represent classes of devices rather than a single device. Thus, even though an improvement category may not appear in the earlier list of recommended programs, it may well be that future inventions will justify a program in that category. For example, this study was unable to identify an electric motor improvement which would be appropriate for ERDA support for pipeline application. However, the possibility always exists that a new idea and/or fresh approach, e.g., the Wanless motor, may appear and offer a previously unidentified opportunity for energy savings. Accordingly, it is recommended that the list and the associated conclusions be maintained by recurrent review and update, so that future opportunities can be exploited as they appear.

Additionally, some limitations on the scope of this study should be noted. This study does not treat the subject of R&D strategies and the selection of certain of the recommended projects for pursuit in preference to the others. This approach was not taken under any delusions regarding the ultimate necessity to think small, that is, to eliminate some projects, reduce others, and defer still others. For the present, we are still thinking big, identifying opportunities to save large amounts of energy and defining the programs that would permit the exploitation of those opportunities.

TABLE 3.0-2

Categories of candidate efficiency improvements

Heat engine improvements

1 - Bottoming engines
2 - Gas turbine regenerators
3 - Internal cooling of internal combustion engines
4 - Slurry-fired engines
5 - Coal-fired engines
6 - Indirect-fired, coal-burning engines

Non-heat engine energy conversion

7 - Fuel cells
8 - Electric motor improvements

Flow-inducer improvements

9 - Pump improvements
10 - Compressor improvements

Slurry pipelines

11 - Coal-water system improvements
12 - Coal-methanol systems
13 - Cryogenic systems
14 - Pneumatic slurries

Drag reduction

15 - Heating
16 - Additives
17 - Internal coatings

Leak prevention

18 - Internal coatings

Operational improvements

19 - Automatic control of transients
20 - Computerized optimization of duty cycles
21 - Improved capital utilization

New concepts

22 - Capsule pipelines
23 - Cryogenic slurry pipelines

The recommended programs are summarized below. Report R-3025 describes each recommended program in greater depth. In each case the program should be coordinated with other active and planned ERDA programs and with other government agencies previously and/or currently engaged in similar or related programs.

1. <u>Gas-fired combined-cycle compressor station</u>

A study and demonstration of a Brayton-Rankine and/or Otto-Rankine combined cycle power plant should be conducted using advanced second or third generation gas turbines or reciprocating gas engines with organic Rankine bottoming cycle. The program, including selection of engine type and size selection, should be primarily oriented to pipeline applications but with broad application potential to utilities and other industrial work.

2. <u>Internally-cooled internal combustion engine</u>

A study and demonstration of an internally-cooled reciprocating internal combustion engine, with bottoming cycle, should be conducted. The objective should be to develop the necessary technology to retrofit existing reciprocating pipeline drivers, and at the same time lay the groundwork for development and application of internally-cooled combustion engines for a broad spectrum of nonpipeline applications.

3. <u>Methanol-coal slurry pipeline</u>

A study and demonstration of a methanol-coal slurry pipeline line should be conducted. Their potential for deliverying coal over long-distance pipelines at relatively low cost, with low net water requirements, and with a broad spectrum of end use options is extremely attractive. Conversion of existing pipelines to coal-oil slurry transport may offer a convenient transition to the coal-methanol mode, and a brief comparison of the two systems should therefore be made.

4. <u>Methanol-coal-slurry-fired and coal-fired engines</u>

A study and experimental work should be conducted to assess the potential for operating gas turbines on methanol-coal slurry and on pulverized coal separated from slurry. The program should supplement previous investigations of hot corrosion and erosion problems in turbines and should include work to identify the fouling mechanism, means of inhibiting fouling, and approaches to minimizing the effect of ash deposits on erosion of turbine hot-end components. The work should be closely coordinated and compatible with the study recommended in 3.3 above relating to methanol-coal slurry pipelines.

5. Indirect-fired coal-burning combined cycle pump station

A study and demonstration should be conducted of fuel cell power sources in combination with DC motors in a liquid pipeline pump station. The pipeline application offers a unique and extremely attractive application for fuel cell power plants for two reasons. First, the use of DC motors in the pipeline application would avoid the need for inverters to convert the fuel cell output to AC. Freed of this burden, the economics of the pipeline application for fuel cells becomes much more attractive than the electric utility application. Second, the nature of petroleum products pipeline operation is such that the use of DC motors would enable an energy saving in the order of 5-10%. The fuel cell, of course, offers the opportunity to realize that improvement. The combination of these two factors indicates that the pipeline is the preferred application for early commercialization of the fuel cell. Accordingly, it is recommended that continuing ERDA fuel cell programs be reconsidered in this light.

6. Fuel cell pump station

A study and demonstration should be conducted of high efficiency, indirect-fired gas turbines with Rankine bottoming cycle, using pulverized coal fuel. The program should capitalize on existing technology in closed Brayton cycle engines which have operated successfully on coal in Europe, but at relatively low efficiency because of limited cycle temperatures. Effort should be concentrated on achieving substantial increases in efficiency through the use of advanced, high-temperature materials in the air heater and the addition of an organic Rankine bottoming system.

7. Drag-reducing additives in liquid pipelines

Further research should be conducted on drag-reducing additives for liquid pipelines, including: basic research into the mechanism of drag reduction; system studies to identify operating problems and assess economic aspects; and a demonstration to prove the soundness of the concept in practical pipeline operation.

8. Internal coatings in pipelines

Demonstrations should be conducted of internal coatings in both gas and liquid pipelines to determine quantitatively their effect on improving pipeline flow efficiencies and to assess the economic potential of their further use in liquid pipeline. The program should begin with analysis and testing to establish the longevity and dependability of present commercial coatings which are applied in place, followed by research and development if necessary, and a demonstration in a full station-to-station section of an operating pipeline.

9. Pneumatic capsule pipelines

In Report R-3027, the future of the pipeline industry is discussed, and it is concluded that freight pipelines, which can move both bulk and packaged dry freight, deserve further study. This latter requirement means that some form of capsule pipeline is needed. It is tentatively concluded that the pneumatic capsule probably has potential for earliest application, but this conclusion is not yet supported by quantitative analysis. It is recommended that a study be performed to assess the potential of the concepts. Section 7.0 of this report contains further discussion of the concepts.

4.0 GOVERNMENT INFLUENCE - PIPELINE REGULATION

4.1 Scope of Pipeline Regulation

Gas pipelines are treated as utility companies and therefore, prior to the recent establishment of the Federal Energy Regulatory Commission, were regulated by the FPC instead of the ICC. However, they are basically transporters and may be regarded as similar to oil pipelines, though there were important differences between FPC and ICC regulation. The principal distinctions are that the FPC does not allow interest as a charge before net income, and that the rate base (valuation) is computed in a straightforward accounting manner under FPC rules. Under ICC rules, the valuation is set by a more complicated and subjective process. With the recent (late 1977) incorporation of both FPC and ICC into the new energy regulatory commission, a more consistent approach to regulation may ultimately be seen. For details of utility regulation, the reader is referred to FPC publication S-231, "Federal and State Commission Jurisdiction and Regulation of Electric, Gas, and Telephone Utilities," 1973.

In addition to regulation of the financial aspects of the business, i.e., tariffs and income, pipelines are regulated in other respects, primarily with regard to safety and environmental impact. There were three cabinet-level departments of the federal government (Transportation, Interior, and Labor) and four independent agencies (ICC, FPC, FEA, and EPA) with some form of jurisdiction over pipelines. Within the Department of the Interior, there were half a dozen subunits which have approval authority, intervenor status, or an obligation to comment upon pipeline construction and operations, and within the Department of Transportation there were at least two.

These agencies, the scope of their jurisdictions, and the jurisdictional incompatibilities, are identified and discussed in Report R-3024. Although numerous incompatibilities were identified, they were not found to be important for the purposes of this study. The important question in this program is whether such incompatibilities exert any inhibitory effect on the introduction of energy-conservative technological innovations. While certain of the regulations themselves are sometimes strongly inhibitory, no such effect has been identified which arises from jurisdictional incompatibilities alone.

The task of dealing with jurisdictional inconsistencies is extremely complex. It is often suggested that when more than a few agencies regulate an activity, all regulation be placed under a single agency. However, this is often fundamentally undesirable, and so the concept arises of what may be called "legitimate jurisdictional overlap." As an example, consider the case of a pipeline crossing a coastal waterway. In addition to the regulation of the operating business aspects of pricing, which are regulated by the FPC or the ICC, it is easy to hypothesize circumstances under which the Office of Pipeline Safety, DoT, and the EPA might have valid regulations to be enforced. In this case, three agencies might be regulating the same activity, each acting to serve a different interest. While these three interests of price, safety, and environmental impact are different, they are all public interests under acts of Congress and their regulations under the law should all apply. Also, it is easy to visualize a situation in which the Fish and Wildlife Service might be required, under still another act of Congress, to impose regulations to save the fish if the pipeline constructor were to propose some detrimental action. Such overlaps of jurisdiction may be termed legitimate in that they are each intended to serve the public interest independent of each other.

While it may be tempting to conclude that one or the other of the regulating agencies should be given overall jurisdiction, there are good reasons to question this course of action. The different interests represented by different agencies, while they are all in the public interest under acts of Congress, are nevertheless conflicting. For example, it is obviously impossible to achieve the lowest price, the greatest safety, and the least environmental impact simultaneously, whether in a pipeline or any other enterprise. Although much evidence shows that the pipeline far exceeds any other mode of transportation in all of these criteria, practical situations demand compromise between what are basically conflicting requirements. Therefore, giving overall responsibility to the protector of one interest may preclude any reasonably optimum compromise. If overall responsibility were given to the safety regulator, for example, the result might be a system which would never cause an injury throughout eternity but at unacceptable financial and environmental penalties.

4.2 Inhibitory Influences of Laws and Regulations

Two bodies of law and regulation exert importance inhibitory influence on the adoption of efficiency improvements and other energy-conservative innovations:

1 - The federal income tax provisions with respect to investment and loss carry-forwards;

2 - The limitations on operating income and dividends.

Oil pipelines operate as common carriers and are regulated by the ICC. Their income is limited to 8% for crude lines and 10% for products. A further limitation on oil lines is that dividends to shipper-owners are limited to 7% by a 1941 consent decree. Since dividends are taken after interest payments, and since the ICC allows interest as an expense before computing the 8% or 10% return, these limits operate in a way similar to, and redundant on, the ICC limits of 8% and 10%. As a practical matter, since virtually all U.S. oil pipelines are shipper-owned, the 7% limit generally applies and any suggested application of the results of this study to oil lines must be examined primarily under this most stringent of the three limits.

With these limits on profitability, it is easy to see why energy-conservative innovations, even very effective ones, may not offer sufficient attraction to the pipeline operator to induce such adoption.

Because of the combination of capital-intensiveness and limited return, full recovery of investment tax credits is an important contributor to RoI. Since the life of an investment credit is seven years, an efficiency improvement cannot possibly recover its own credit. Therefore, the decision to accept or reject a prospective improvement can almost never be made on a stand-alone basis, even in the first approximation, since it may be strongly influenced by the way its tax credit life overlaps others, either already on the books or contemplated. It may depend on whether the owning company has other enterprises which can absorb the tax credit.

Also, a pipeline with a large initial investment and a low initial throughput may find that if it is highly leveraged, it cannot recover all of its initial tax credit. In this case, the RoI can be improved by reducing leverage, and the optimum initial equity position, i.e., that which maximizes RoI, may be as high as 40 or even 50%. Until an operator can see how a situation is likely to resolve itself, it may be difficult to interest him in efficiency improvements, even those for which a solid case can be made on paper. These influences are further discussed in Report R-3024.

In summary, then, the effect of laws and regulations on innovations is indeterminate in that it depends on the specifics of the situation into which the innovation is to be introduced. Depending on those specifics, the regulatory effect may range anywhere between completely neutral and prohibitively inhibitory.

4.3 Recommendations on Pipeline Regulation

The conclusion which emerged from the preceding discussion was that if changes to the regulatory process are to be made which will effectively promote energy conservation, they must be sufficiently strong in the motivation which they stimulate, and in the breadth of their applicability, that the confusion and ambiguity just described is neutralized and overcome. Report R-3024 presents two new regulatory concepts for achieving this objective which are also summarized below:

1 - Introduction of what is termed a "national equivalent value" for natural gas into the tradeoff studies on which the acceptability of energy-conservative innovations for entry into the pipeline companies' rate base is judged. The result would be that any innovation that would be cost effective at the national equivalent value would be acceptable as a legitimate addition to the rate base. Under the present dispensation, the cost-effectiveness of a prospective innovation must be established under the price actually paid for the gas. That price often was established by contract years earlier at what is, by comparison today, a very low price. The result is that, even though new gas is presently valued at $1.46/Mcf, an innovation may have to prove its cost-effectiveness at 35¢/Mcf to be an acceptable addition to the rate base. In other words, gas whose replacement is recognized as worth at least $1.46 continues to be wasted because an artificially low value is used to determine its admissibility into the rate base.

2 - Introduction of what is termed a "valuation allowance," above the regularly approved cost of an energy-conservative innovation, into the rate base, along with the approved cost itself. While this allowance could be any amount, it is suggested that the allowance be equal to the approved cost, so that the addition to the rate base would be twice the cost. The result would be that the company could then make up to twice as much profit by saving energy as by wasting it.

The philosophy underlying the first measure is that gas which is saved is equal in value to new gas which, eventually at least, must replace it. A foot of gas saved is equal in value to the first foot of extracted gas from a new well. The argument can be made that, since the natural gas resource will certainly be totally depleted before the coal resource, the equivalent replacement value is the cost of converting coal to high-Btu gas which at 1977 prices and technology is about $4.40/Mcf.

The second proposal simply allows the companies to realize sufficient potential profit from energy conservation to ensure that they are motivated to do it, no matter how confusing or ambiguous their particular tax situation may be.

An important advantage of these proposals is that they require only a single change in the law. Thereafter, the ICC and FPC procedures and the operation of the consent decree are unchanged after the insertion of the new values into the rate base.

Considerable further research will be necessary to develop the foregoing recommendations into practical legislative proposals. It is strongly recommended that this research be undertaken immediately.

These recommendations deal only with the motivation of energy-conservative capital investments. Also needed is a recommendation to stimulate energy-conservative operational techniques, i.e., those which increase operating cost. Presently, such innovations are introduced only if the energy saved offsets the operating cost burden at the regulated value of energy. In the recommendations only a single change in the law is needed; once the rate base allowance is made, nothing is done differently than before, so that the people who administer the law do not have to understand and interpret the new law. No such simple and straightforward device for motivating the conservation of energy in pipeline operation has been conceived in the course of this study, though this may be achieved with further study. Accordingly, the research recommended above should also address the possibility of stimulation of energy-conservative operational measures.

5.0 GOVERNMENT INFLUENCE - THE POWER OF EMINENT DOMAIN

An old technology which has emerged in recent years for the long-distance transport of coal through pipelines is the slurry pipeline. Slurry pipelines have been used for many years to move solid materials, e.g., ore and wet concrete, over relatively short distances, and over the last 20 years they have been applied in the longer-distance (100 miles or more)movement of coal.

A slurry is a suspension of small, solid particles in a fluid, either liquid or gas. The coal slurry pipelines that have been built use water as the carrier fluid, although as noted elsewhere in this report, other fluids hold even greater potential for savings of energy and of petroleum-derived fuels.

5.1 Identification of the Fundamental Issue

The growth of coal-slurry pipelines into new markets is prevented by the almost universal refusal of railroads to permit the slurry pipelines to cross their right of way (RoW). In general, the only way for the pipelines to overcome that obstacle is by exercise of the right of eminent domain (ED), and the pipeline promoters and their supporters have been seeking legislation to acquire that right. These efforts have been opposed by the railroads. As with almost any controversy, the debate has expanded to include peripheral issues, in this case those of environmental disruption and impact, water movement, safety, employment, and energy conservation.

There are three requirements for the exercise of eminent domain:

1) That the condemned property be taken only for public use.
2) That the action be carried out in accordance with due process of law.
3) That just compensation be given.

Emiment domain power exists at both state and federal levels. The general principle on which both are justified is that of the public interest. However, the public interest within an individual state is often entirely different from the public interest of the nation as a whole (national interest). This study is directed toward the national interest; analysis of the many and often conflicting interests of the individual states is not attempted here.

The use of eminent domain is not limited to transportation systems or to common carriers. However, for a transportation system to qualify as public use, it is generally conceded that it must operate as a common carrier, serving without favor all who tender commodities for transport in accordance with its published tariffs. Traditionally, endowment of the federal ED power on a private enterprise has been subject to certain obligations and restrictions. In the case of common carriers, these have included the requirement to operate under federal regulation. The slurry pipeline promoters have accepted this obligation, along with that of operating as a common carrier. Although there are questions as to how well and meaningfully they will apply in practice, there does not appear to be any fundamental principle at issue in how the slurry pipelines will operate after they are built.

The central issue, then, which is or should be the basis for resolution of the controversy, is whether it is in the national interest to endow the slurry pipelines with the federal power of eminent domain. If a clear and conclusive finding can be made that such endowment is not against the national interest, then potential solutions are available to resolve the peripheral issues, and the power should be granted to the pipelines.

The bills that have been introduced in previous Congresses to grant the federal ED power have opened with statements of findings which say, in effect, that it is in the national interet to increase the use of domestic coal and that "in some situations" such use would be "facilitated" by the construction of pipelines. These situations are to be identified by the Secretary of the Interior by issuance of a certificate of public convenience and necessity. The Secretary is directed to consult with other government agencies, to consider "the record as a whole," and to make "independent findings" based on four criteria:

1) How the project helps national coal utilization.
2) Potential delays if the ED power is withheld.
3) Environmental disruption.
4) "Water requirements and other impacts" on the coal mining area.

To the pipeline opponents, these statements of findings in the national interest are much too weak to justify passage, and some powerful Congressional committee members have agreed with them because they have been successful in preventing the issue from coming to a vote.

It is helpful to contrast the present case with an earlier one, that of gas pipelines. In that case, the need was clear and there was no other practical way to move the gas. Hence, it was not particularly difficult for the Congress to reach a finding of positive national interest.

In the present case, despite some valid questions as to their capability, it seems probable that the railroads can move all the Western coal to market, provided that the public in towns and countryside along the way is willing to accept the consequent continuous disruption of its business and social life. The basic question, then, is why the national interest is better served by moving a part, perhaps 10%, of the coal by pipeline instead of by rail.

5.2 Conclusions

5.2.1 The Fundamental Issue

The principal conclusion of this study is that, on balance, the national interest is better served by granting the federal power of eminent domain to the slurry pipelines than by its denial. However, the case is by no means conclusive, and the conclusion itself is further subject to two important provisos:

1) Grant of the power should be made with the explicit reservation that it does not imply Congressional sponsorship or endorsement in principle of the use of Western water for slurry pipelines. As discussed in Report R-3023, the water issue with regard to slurry pipelines is a false issue. Even the driest states make some allocation of water, usually that which is non-economic, for agriculture, for industrial uses. If a state chooses to assign some of its industrial allotment to slurry pipelines, there is no apparent reason for anyone else to be concerned. If a valid question does arise, it should be debated in another court. To ensure this separation of the issues, however, it is necessary that the Congress, in granting the power, make clear that its intent is not to decree or endorse state water allocations to future pipelines.

2) Since the only realistic scenario by which the pipelines could become wards of the state is that buyers would default on the 30-year contracts to "take or pay for" the coal, the grant of ED power should require a finding that the coal purchase contract is valid and realistic for the amortization life of the project.

The foregoing conclusion is derived from study of all the subissues, called peripheral issues for convenience. As shown in the next section, on some of these issues rail transport makes a better case, and on others, pipeline transport is to be preferred. The conclusion was formulated by subjective balancing of those individual outcomes. Quasi-quantitative balancing processes, e.g., point scoring techniques, have not been used.

Since the railroads disagree with this conclusion, even with its provisos, it is only fair to hear a complete exposition of their side of the argument. Such a statement, by one of the best qualified railroad spokesmen, is presented in its entirety in Report R-3023, which the interested reader should consult before formulating his final conclusions.

5.2.2 The Peripheral Issues

5.2.2.1 Economic issues

There are a number of economic issues to be considered, including the cost of service, the price of service, the feasibility of financing both transport modes, the relative susceptibility of the modes to inflation, and the possibility of one or both of the modes becoming financial wards of the state.

In this study, it has been concluded that:

1 - While the true, longrun costs of both pipeline and rail service are still unknown, the rail costs are subject to greater uncertainties.

2 - Within the precision of available estimates, the pipelines are economic only under certain limited circumstances. However, if present railroad pricing policy continues, the pipelines will be cheaper than unit trains in additional situations.

3 - The additional capability of the pipelines, with the comcomitant pressure on prices, will exert a healthy, limiting influence on tariff escalation.

4 - In no case can the pipelines capture enough traffic to damage the railroads. Coal-hauling railroads are destined for a period of booming prosperity, with or without pipelines.

5 - The railroads are shifting much of the burden of financing their expanded capability to their customers, the electric utilities, by forcing them to buy the rolling stock. Many of the utilities are already reaching the limits of their ability to finance new projects, just to build the plants to burn the coal. They are ill-prepared to assume the railroads' financing duties. The pipeline, in offering a new avenue to the capital market, may benefit the utility by relief from this additional burden.

Since the slurry pipelines will offer some economic benefits to significant segments of the nation, and will do no harm to the others, it is concluded that they are in the national economic interest.

5.2.2.2 Other issues

In Sections 5.4 through 5.9 of Report R-3023, a number of additional issues are discussed. For the purposes of this summary, only the principal conclusions are listed below.

1. Water supply. An issue that has aroused considerable emotion and inspired much polemic is that of water for the pipelines. It is a conclusion of this study that this is a false issue which has no bearing here. As noted in Section 5.1 above, even the driest state allocates some of its water for industrial use, and if that is what a state wants to do with water which it owns, there is no apparent reason for the federal government to intrude. As also noted above, however, the Congress should not allow itself to be interpreted as decreeing, sponsoring, or even necessarily endorsing, such actions by the states.

Accordingly, it is concluded that eminent domain for slurry pipelines would not by itself adversely affect the national interest by misuse of water.

2. Energy consumption. The existing Black Mesa pipeline consumes far more energy per ton-mile than a diesel-powered unit

train. With the benefit of scale and current technology, and with coal far moister than Black Mesa coal as mined, the next pipeline can reduce that disadvantage to about 20% or less (something over 800 Btu/ton-mile for the pipeline and somewhat less than 700 for the unit train).

When the precious character of diesel fuel is recognized, i.e., its petroleum origin, and both train and pipeline are constrained to operate on coal-derived energy, the advantage shifts to about 50% (1200 Btu/ton-mile vs 800) in favor of the pipeline. Since it is considered better to use 800 Btu of coal than 700 Btu, or even much less, of petroleum energy, it is concluded that the slurry pipelines will have no adverse energy effect on the national interest.

3. Employment. The ETSI line is expected to employ 355 people. The addition of approximately 5000 people-years of employment that will be provided by construction of the pipeline, or about 170 people-years/year over the 30-year life of the project, raises this total to 525. The railroad employment is 3 to 4 times that figure.

The obvious conclusion is that the pipelines will have an adverse effect on national employment.

4. Safety. The pipeline is safer than the railroad by an order of magnitude, even when account is taken of the accidents during pipeline construction. With the certainty of the statistics of large numbers, a decision to move all the Western coal on the railroads will in effect condemn to death over the next 30 years several thousand people who would otherwise survive. Clearly, from the point of view of safety, the pipeline is in the national interest.

5. Environmental disruption. In normal operation, the pipeline imposes far less impact on the environment than unit trains. In non-normal operation, the possibility of a large slurry spill,

as demonstrated by trillions of ton-miles of experience in oil pipelines, is extremely remote. Nevertheless, such an environmental threat has not yet been analyzed in detail. However, the means are at hand to defeat that (and any other) threat to any specified level of risk. A possible approach to balancing that risk against the corresponding risk from coal movement by unit train, suggested in Report R-3023, is to require that the pipeline defeat its combined environmental and safety threats to the same equivalent level, in terms of human life, as that of the railroad. The analysis performed in this study, though very preliminary and subject to revision under detailed analysis, indicates strongly that the pipeline, when built and operated to the normal standards of the pipeline industry, will be far less undesirable under this criterion than the unit trains.

Accordingly, it is concluded that, from the viewpoint of environmental disruption, the slurry pipelines are in the national interest.

6.0 AN ECONOMIC MODEL OF PIPELINE TRANSPORTATION SYSTEMS

At the beginning of this study, a very considerable effort was devoted to collecting data and developing a model of a pipeline system. An early decision was that the model should be a dynamic simulator by which economic studies could be performed to the same depth and detail that are employed by pipeline companies in their regular business. The model which resulted from this effort is briefly described below. It was used in every phase of this study, both in developing new conclusions and in quantitative exploration of hypotheses and scenarios.

The PEM simulates the operational dynamics of a pipeline in a quasi steady state approximation. Inputs are of two general classes: the system to be simulated and the postulated market projection. The system to be simulated is in turn characterized by two structures: the physical structure and the financial structure.

The outputs of the PEM are of two kinds: the energetics and the economics. These latter are available in a number of report formats, and the user may call any, all, or none of them. There is some duplication of commonly requested output variables among the output reports, so that for many studies, only one or two reports need be called because these variables are available through two or more reports.

The PEM consists of two major submodels: the fluidics (physical) model and the financial model. The fluidics model is referred to hereafter under the generic name PEP (Pipeline Energy Program), while the financial model is referred to as JFM, the code name by which it is recognized by the S^3 UNIVAC 1108 computer executive system.

The interested reader is referred to reports R-3021 and R-3069 of this series for further detail. R-3021 discusses the purpose for which the model was developed, the rationale for selection of of a dynamic simulator, and the applications in which the model was used. R-3069 is the user's manual and should be consulted by those who expect to be directly involved in exercising the model.

6.1 Fluidics Models

The fluidics model accepts as input the physical description of the system, e.g., segment lengths, diameters, elevation profile, bend index, pump characteristics, and fluid properties. Also input is the market projection which the investigator postulates for the simulation, specified as a projection of throughput and product mix. The model calculates the required pressure profile, selects the pumps, and calculates the energy consumed in useful work to overcome flow resistance and the energy wasted in throttling.

It is necessary to have several fluidics models if all types of pipelines are to be treated. Single-phase or gas flow, two-phase flow, non-Newtonian flow, with or without heating and/or cooling, must all be accounted for as the situation may require. A file is created in the computer system for the output of the fluidics model. When JFM is run, it accesses the fluidics output file. Thus, there is no direct interaction between the two submodels, and accordingly, no restraint on what analytic program is used for the fluidics model. Any characterization of the fluidic behavior can be used, so long as its output is constituted in the appropriate file format for access by JFM. For the gas pipeline simulations, a proprietary Pipetech code is used and the output is formatted manually and stored in the S^3 computer. This code is available at a moderate royalty for use by other organizations. For the liquid cases, several variations are available on the S^3 computer of a basic pipeline fluidics model which was developed under this contract by Dr. Mary Baker of S^3 and Mr. Wayne Baker of Pipetech. The Pipetech version of this code is known as LIQPL, and its user's manual is presented in Appendix A of Report R-3021. The version which is in the S^3 computer is called Pipeline Energy Program (PEP).

6.2 The Financial Model

The financial model is the S^3 financial projection model, developed by Dr. Joseph Masso of S^3, and referred to as JFM, which accepts as input the output of the fluidics model and the financial characterization of the system. The JFM output is the set of financial results which was described earlier.

In the development of JFM, care was taken to construct a general business model, i.e., one which is not pipeline-peculiar. This objective was accomplished by building in options which allow the user to remove the regulatory constraints. These options are described in Section 14 of Report R-3021. The defaults for these options, ICC+F, FPC+F, etc., enable the program to simulate any business venture.

6.3 The Reference Systems

A simulator can serve a useful purpose only if it is mated with a simulatee. Stated equivalently, a model only has value as it reveals something about its prototype. For this study the prototype (simulatee) is a pipeline which is termed a reference system. Five reference systems were designed: crude oil, petroleum products, natural gas, coal-water slurry, and water. These designs are not hypothetical; they were developed by Pipetech by modifying an actual pipeline system design. Thus, their costs are known with much better accuracy than for any hypothetical case.

7.0 FUTURE OF THE PIPELINE INDUSTRY

7.1 The Scenario for Conventional Growth

The consensus of industry opinion is that, over the rest of the 21st Century, the amounts of oil and gas produced in the United States will decline, while demand continues to increase. In both cases, some of the shortfall will be offset by imports and a small amount of synthetics, so that the total amount of oil and gas delivered to customers will not decline and will probably increase somewhat.

The consequence of this scenario for the pipeline industry is that total ton-miles of traffic will increase only slightly, but total miles of operating system will continue to increase more strongly because for a while at least, old lines will be retired from service at a slower rate than new lines are brought into service. Later, as fewer new discoveries are made and old sources are depleted, retirements will exceed new additions and the trend will reverse. Thus, for a number of years yet, moderate growth will continue, but at a declining rate of increase. There is no booming expansion in the future of the pipeline industry, unless some completely new applications can be found, i.e., unless ways can be found to move other commodities than oil and gas.

7.2 The Scenario for Unconventional Growth

When one reflects on the strong and attractive advantages of pipeline transport, it is easy to become wistful. Pipelines generally are much the cheapest, quietest, least obtrusive, safest, and most reliable mode of freight transport. The compensating offsets are that they are also the slowest, and they can only, within the limits of today's applications, move fluids and a few powdered solids. If a way could be found to enable them to move other commodities and packaged freight, at moderately faster speeds, then the advantages enumerated above would seem to portend a large expansion of the pipeline industry.

It is concluded that such pipelines, referred to here as freight pipelines, are most likely to materialize in two forms: slurry pipelines and capsule pipelines. As is discussed in depth in Report R-3023 of this series (see Table 1.1-1 above), the pressures for slurry pipelines are developing and the battle lines are drawn. As is discussed in Report R-3027 of this series, capsule pipelines may possess even more promising potential, but there appears to be little likelihood that comparable pressures for them will develop without a DoE-sponsored program of research, development and demonstration. Further study of the concept is strongly recommended.

7.3 Recommendations

In this brief analysis, it was not possible to perform quantitative performance comparisons or systems studies of the various concepts for freight pipelines and accordingly, such analysis was not attempted. Instead, an attempt was made, by an examination of all modes of freight transport and of the effects of modal shifts between them, to identify the general performance envelope into which they must fall if they are to be economically competitive. This analysis indicated that system technical performance objectives should include:

1 - Capability to accommodate both packaged freight of medium size and bulk commodities;
2 - An average speed of 20 mph or more;
3 - Capability to ascend and descend steep grades;
4 - Capability of high throughput.

Requirement 1 calls for a capsule system. Requirements 2 and 3 determine capsule separation. Requirement 4 is determined by the economic analysis.

These requirements are in some ways contradictory. For example, requirement 3 calls for wide capsule spacing and limited speed, in contradiction to requirements 1, 3 and 4. Further study is required to examine these and other tradeoffs, and to identify a concept for analysis and possibly for an R,D&D program.

In Report R-3025 of this series (see Table 1.1-1 above), the broad outlines were presented of the programs of research, development, and demonstration which are needed to realize the energy-conservative potential of the technological innovations that were discussed in that report. In each case, the recommended program consists of six phases:

1 - Identification of the opportunity
2 - Concept validation
3 - Research and development
4 - System design
5 - Demonstrator construction
6 - Demonstrator operation

The work reported here constitutes Phase 1, Identification of the opportunity. It is strongly recommended that Phase 2, Concept validation, be implemented. That phase, in turn, should include the five subphases indicated in the generic schedule shown in Fig. 7.3-1. If available resources cannot support the entire Phase 2 immediately, then at the very least, Subphase 1, opportunity confirmation, and a preliminary Subphase 5, Program definition, should be performed.

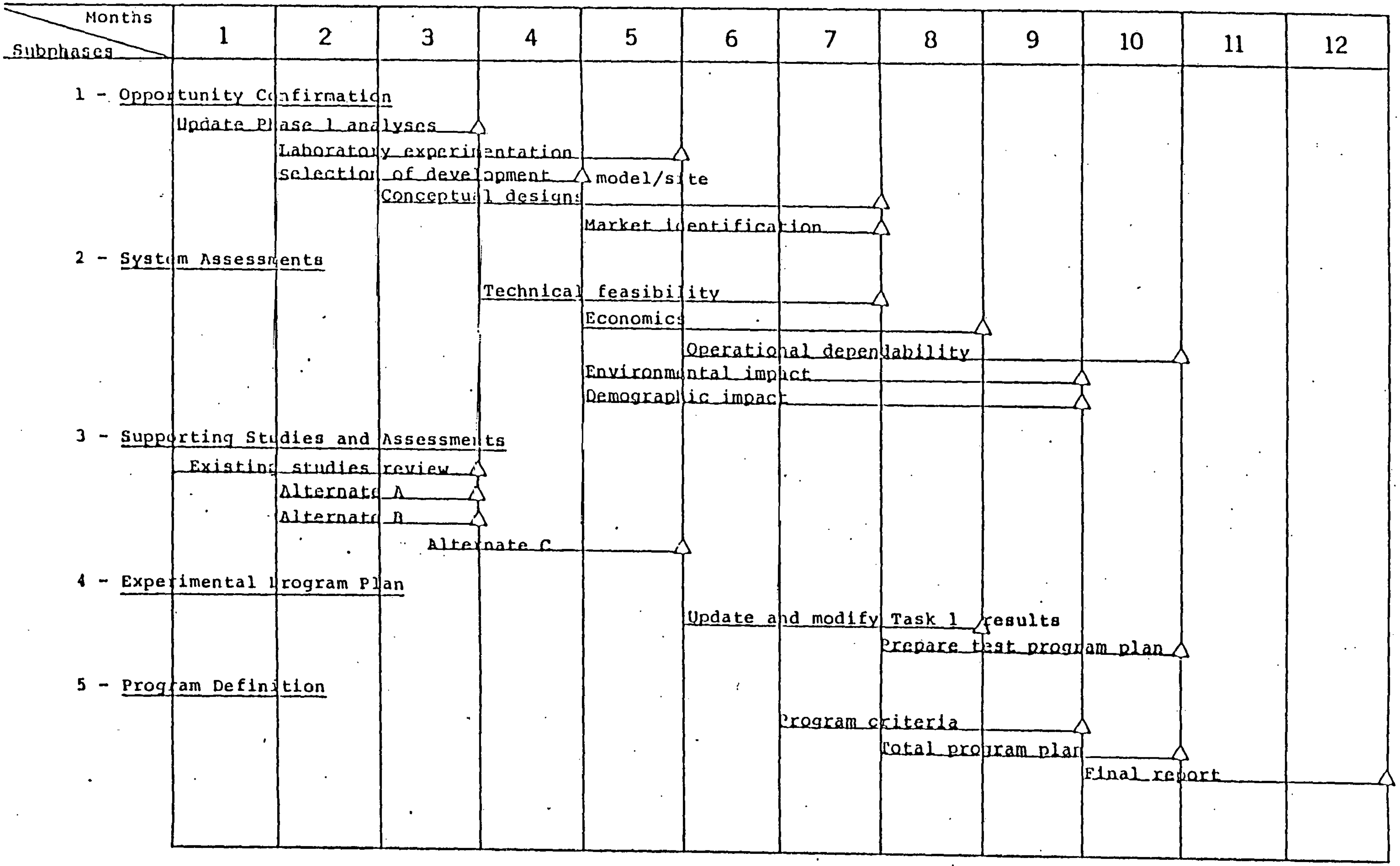

Figure 7.3-1 -Generic Phase 2 Schedule

R-3020