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ROADWAY DECISION MAKING AND IMPLICATIONS FOR ENERGY USE: SOME ECONOMIC CONSIDERATIONS

Ultimately, almost all decisions concerning location, basic design, and materials used in constructing a roadway have implications for energy consumption. Decisions made today in which one alternative is chosen over another influence energy consumption now and, perhaps more important, have ramifications that will affect energy consumption for years to come.

This paper does not present new data or a detailed methodology with which an engineer or planner can make a specific decision that is optimal in its energy consequences. The great diversity of design problems clearly makes this impossible. Instead, energy costs are discussed in relation to the many other factor costs that are considered as a part of the complex resource allocation problem that is at the center of every roadway design problem. The goal of this paper is to help those concerned with transportation planning to make decisions that are justified on economic grounds. To make such a decision requires knowledge of all the costs and benefits (defined in the broadest terms) associated with the project. Given uncertainty regarding the future, such decisions are always difficult. An intelligent consideration of the place of energy as a variable in the decision-making process requires knowledge of some of its unique characteristics.

ENERGY AS A FACTOR COST

Similarities to Costs of Other Inputs

Building a road requires combining a vast number of inputs, each of which has a price attached to it. Land, materials, equipment, labor, and energy may be used in an almost infinite number of different proportions. The quantity of a particular factor of production that is used is largely dependent on the price of that factor. Achieving a goal of minimization of total costs requires substituting less expensive inputs for those that are more expensive. This elementary concept of economizing on the use of high-cost resources is one of the most basic principles of economics, and it needs to be kept firmly in mind when energy is considered. Energy, like all other inputs, may be used sparingly or lavishly. Some energy must be used, of course, but energy that becomes expensive will be used in small quantities compared to present levels. In this regard, energy is like any other input.

Special Considerations

Several considerations are particularly applicable to energy as a factor of production. The present price of energy does not reflect its true value to society. Prices for both oil and natural gas are in part determined by the government rather than through a free market that uses prices to balance supply and demand. Put quite simply, energy has been too cheap. Through the first step toward complete deregulation, energy is beginning to assume a price closer to its true market value. Today, however, regulation of prices must still be considered. Predicting future prices of energy must involve predictions concerning the political process and the speed with which deregulation either does or does not occur. It must also try to deal with the vagaries of resource exploration and extraction.

The price of energy is also highly dependent on the actions of foreign countries. The unpredictable actions of foreign oil producing and exporting countries have a profound influence on the energy prices that American consumers face. Energy is in many ways a "special case" because of this element of uncertainty concerning future prices. The inherent unpredictability of foreign domestic politics means that those who are making decisions involving the use of energy at some future date are faced with a dilemma. That dilemma involves a choice between making a pessimistic or an optimistic assumption concerning the future price of energy. Although no prediction is made here concerning the future price of energy (other than a prediction that it will go up), a framework is established for examining energy and its importance in a broad sense. Dealing with energy intelligently requires a knowledge of the many areas of use and all of the direct and indirect costs related to energy consumption.

Broad View of Costs

A narrow view of the energy costs associated with a roadway looks only at the first costs of various alternatives. This approach involves, for example, choosing one type of surface over another because its energy content, perhaps measured in Btu/yd^2 (J/m^2), is less. First costs are an important consideration, and the various paving materials, base materials, and construction methods that can be used for a given project can vary greatly in terms of energy used. First costs are discussed later, but at this point it is important to note that an economic analysis of energy must go beyond mere consideration of first costs.

Those familiar with economic analysis of alternative investments are certainly familiar with life-cycle costs. In the context of energy costs associated with roadways, life-cycle costing considers energy used in construction, raw materials, maintenance, resurfacing, and replacement. (New technologies for pavement "recycling" may make the line between resurfacing and replacement unclear.) A life-cycle approach to energy must incorporate estimates of quantities of energy used during the life of the road and the cost of the energy at the time of use. A discounting procedure is used to diminish the importance of dollars spent in the future relative to those spent today. With rising energy costs, a failure to account for future energy use associated with a project can result in a serious understatement of true total energy costs. Energy use by vehicles on roadways is a factor that necessitates an approach even broader than direct life-cycle costing of alternatives. If energy consumption were not dependent partially on the type of road, then this would be a constant among construction alternatives and would not have to be considered. However, the vertical profile, horizontal alignment, and roadway characteristics all influence the fuel consumption of vehicles using a particular road, and 2 roads can vary considerably in characteristics influencing operating costs. On a heavily traveled road with a 20-year life, the additional energy costs that can result from decisions made during the design stage can potentially be of a magnitude that dwarfs any energy costs associated with construction and maintenance.

Energy Consumption Associated With Roadways

In keeping with the broad approach to energy usage being advocated, a broad definition of a roadway is clearly needed. Energy will be used at every stage in the life of a roadway from the initial grading operations through construction, maintenance, resurfacing, reconstruction, or retirement. Energy is also used to produce and transport every material—from the base materials to the pavement surface. Choices involving the design of bridges, dividers, drainage systems, and even landscaping schemes will all have consequences for energy use at the initial stages as well as during the life of the roadway. Energy costs associated with all of these components of a roadway should be considered.

METHODS OF ECONOMIZING ON THE USE OF ENERGY

Industrial Energy Conservation

A brief consideration of efforts now under way to conserve energy in the industrial sector suggests that there are similarities between conservation opportunities in this area and those in the roadway area. Industrial energy conservation can be achieved through actions that fall into 3 broad categories.

Housekeeping Measures

Considerable conservation potential exists in the industrial sector through adoption of what are often called housekeeping measures. This housekeeping category involves changes in procedures and closer control of industrial processes. Reducing lighting and space heating levels in industrial plants, closer monitoring of processes, repair of steam leaks, and proper maintenance of equipment are examples of changes in procedure that have proved useful in reducing energy use.

Non-Output-Related Investments

A second category of industrial energy conservation potential involves capital expenditures for equipment specifically designed to reduce that portion of energy that is needlessly wasted. These are often called non-output-related investments because they do not have an effect on the quantity or quality of output produced. The revenues that are produced by such investments come in the form of dollars not spent on energy. Examples of such investments include insulation applied to various areas of process heat loss, recuperators and regenerators designed to return waste heat to the process, and boilers that use waste heat to supply steam.

Capital Turnover

The third general area of industrial conservation potential is usually called capital turnover. Energy use is reduced by installation of new equipment and construction of new plants that are inherently more efficient in their use of energy. The reduction in energy may come about either through a better designed piece of equipment installed as a part of an existing process or through adoption of an entirely new process. The new Alcoa process for producing aluminum is an example of an entirely new way of producing a product with a considerable savings in energy. Although capital turnover may be accelerated by government programs that stimulate investment, this area of conservation potential is usually considered to be effective in the long run because of market forces and technological progress.

Potential Areas for Saving Roadway Energy

Analogous to the housekeeping and non-output-related investment categories in the industrial sector are 2 areas in which energy savings can be achieved in roadways. The basic distribution is between actions involving capital use and factor substitution and measures aimed at stopping waste through little or no use of capital. In both cases, however, energy conservation measures must be assessed in terms of their returns relative to costs. If the full costs associated with a project exceed the resulting benefits, then the project is not economically justifiable and should not be pursued. Experience with energy conservation measures in the industrial, residential, and commercial sectors suggests that there are certain to be numerous economically justifiable opportunities for reducing energy use associated with roadways that are not being pursued.

Noncapital Areas

Numerous changes in procedure are possible that involve little or no expenditure of capital and yield potentially large benefits in the energy costs associated with the construction, maintenance, resurfacing, or reconstruction of roadways. A list of possible ways to change procedures and thereby reduce energy use includes the following:

1. Use maintenance vehicles more judiciously,
2. Use vehicles with better fuel economy,
3. Minimize double handling of materials during construction,
4. Reduce frequency of maintenance operations if adverse long-run effects are not likely to result,
5. Maintain vehicles and equipment better, and
6. Minimize waste of materials.

The thing that these various procedural changes have in common is a savings in energy with minimum trade-offs involving greater use of other factors. Additional labor is required with many types of procedural changes, but the benefits in the form of reduced energy expenditures are often large in relation to the minimal costs involved. Procedural changes aimed at reducing energy waste have this characteristic in common with other waste elimination measures.

Factor Substitution

A second major area of potential for saving energy involves factor substitutions of varying degrees of complexity. Within this category are direct substitutions of capital for energy as well as more subtle forms of substitution of one material for another that have life-cycle energy savings consequences. The substitution of one material for another to save energy involves some complex considerations concerning the true costs and benefits associated with such a substitution. A life-cycle approach to costs and benefits is essential to a proper evaluation of the trade-offs associated with choosing one construction alternative over another. First costs, maintenance costs, and user operating costs must all be considered.

A direct form of substituting capital for energy can involve greater use of capital in initial construction and maintenance in order to save fuel costs of vehicles using a roadway. For example, the choice of a lesser grade on a road will certainly tend toward minimization of user costs, but usually at the expense of greater construction costs. Minimization of user fuel costs requires a perfectly flat road with an even and smooth surface that is constantly maintained. Even extremely heavy traffic composed of vehicles that use high-priced fuel and have low fuel economy will not justify the huge capital costs that are sometimes required to minimize user fuel costs. The trade-offs are obvious, and roads designed today should incorporate a consideration of both probable fuel costs and traffic levels likely to be associated with a particular road during its lifetime. Greater first cost in order to reduce life-cycle costs may be justifiable.

Substitution of construction materials is often considered on the basis of cost minimization. The issues involved are certainly as complex as those in the case of minimization of user fuel cost through greater initial construction costs. The considerations relevant to comparing the energy implications of an asphalt and a cement pavement will serve to illustrate a number of points that apply equally to many different areas of construction and maintenance decision making.

Under an assumption of perfect knowledge, it is possible to determine the exact cost of an asphalt concrete or a portland cement concrete pavement adequate to meet the requirements of a particular situation. Energy contents as well as prices are associated with each surface, and these can be calculated in a rough way on the basis of the energy content of asphalt, cement, steel, aggregate, and the transportation and construction costs associated with each. For a comparison of the first costs associated with each pavement, it is the direct dollar costs and not the energy contents of the 2 materials that are the relevant factor. The price charged for the 2 materials will reflect, in part, the energy used in the manufacture and the price paid for the energy. (This relation between product prices and energy is considered in greater detail in the next section.) It is not normally within the realm of an engineer or planner to be concerned with the energy contents of pavement when first costs are examined.

The maintenance program required for a particular type of pavement in a specific application has serious implications for the total energy consumption associated with a particular roadway. For example, first-cost minimization may be achieved through use of an asphalt pavement in a particular situation. However, once the pavement is in place, a certain maintenance program will be required to keep the road in good condition. The high cost of maintaining the surface chosen relative to an alternative surface can mean that the first-cost advantage can be offset by greater life-cycle costs. A greater deterioration of the surface can be deemed acceptable, of course, and, although this may make total costs of one surface appear favorable, increased user fuel costs may be associated with such a decision.

This first-cost and life-cycle cost distinction is a common one and is certainly applicable to costs other than energy. It is particularly important in the case of energy costs because of the previously mentioned volatile nature of energy prices. The long-term commitment to a certain maintenance program means that future energy prices of alternative pavement and maintenance combinations must be considered. Materials required for future maintenance programs may be energy intensive and may increase in price because of increases in energy price. Both increases in prices of maintenance materials and the direct effects of fuel price increases on maintenance vehicle operating expenses must be considered as a part of a life-cycle determination of costs and benefits. Energy costs saved in the future are a benefit that must be weighed relative to first costs. Examples of possible material substitution decisions with consequences for first and life-cycle energy costs are numerous. A list of these may include

1. Use of blended cements that are less energy intensive;
2. Use of less energy-intensive base materials;
3. Different coatings on pipe and other metal roadway elements;
4. Different materials for guardrails, railroad crossings, bridges, and other features;
5. Changes in specifications for aggregates;
6. Reducing unnecessarily stringent specifications for materials (where life-cycle trade-offs are not adverse); and
7. Use of asphalt emulsions instead of hot mix.

Energy and Future Costs of Roadway Materials

As stated earlier, future energy prices are dependent on both foreign and domestic politics, as well as on the vagaries of resource discovery, to a degree that makes predictions hazardous. Future energy prices will be important in estimating direct fuel costs associated with maintenance programs that are likely to be required to maintain a particular roadway. They will also be important as one determinant of future prices of materials likely to be needed for future maintenance. In cases where a considerable time lag exists between project planning and actual construction, future energy prices may be relevant to evaluating probable first costs of alternative roadway designs. This section briefly outlines a framework for evaluating the relation between energy prices and product prices.

The extent to which increases in energy prices will result in increased product prices in a particular industry is dependent upon

1. Mix of fuel types used in the industry,
2. Price increases for various fuel types,
3. Amount of energy used to produce a unit of output,
4. Degree to which industry can (or chooses to) pass through energy price increases, and
5. In the long run, degree to which the efficiency energy use increases in the industry (through conservation measures and/or more modern equipment or both).

Table 1 (1) gives energy consumption profiles for a number of large energy-consuming industries. The steel, chemical, cement, and aluminum industries all produce products that are used in roadway construction. The large variations among industries in dependence on the various fuel types are apparent. There is also considerable regional variation in fuel consumption in the patterns. Figure 1 (2) shows historical data on the efficiency increases that have occurred in the industrial sector. Interindustry comparisons of these energy/output (E/O) ratios also show the differences in the energy required to produce a unit of output.

A set of calculations is provided for energy price increases associated with President Ford's 1974 proposed deregulation and tax program [price deregulation of domestic oil and new natural gas supplies and excise taxes on crude oil, imported oil, natural gas liquids, and natural gas of \$2.00, \$2.00, and \$1.45/barrel (\$12.50, \$12.50, and \$9.06/m^3) and \$0.37/1000 ft^3 (\$0.01/1000 m^3) respectively]. The energy price increases translate into product price increases (with an assumption of 100 percent pass-through). The nature of future variation among industries in product price increases will depend on the relative price increases in oil, gas, and coal. The size of future product price increases will depend, of course, on the size of future energy price increases. These can obviously be considerably larger than those in the deregulation and tax program, which is used here as an example. Two cases are calculated (Tables 2, 3, and 4): one in which coal prices rise in response to increases in gas and oil prices and one in which coal prices remain constant.

The calculation of the impact of energy price increases on product prices is a 3-step process. The first step (Table 2) involves estimating increases in the price of the various fuel types. The second step (Table 3) involves calculating the base energy price and energy price increases in each industry based on the industry's mix of fuel types. That is, industries that are large users of a fuel (such as coal in case 1) that is not increasing in price will not face large energy price increases. The final step involves use of energy/output coefficients as a measure of the importance of energy as a factor of production. The increase in product prices implied by increasing energy prices (assuming 100 percent pass-through) is calculated and given in Table 4. Increases in prices are substantially higher in the steel and cement industries if coal prices are assumed to rise in response to rising gas and oil prices.

These calculations show the way in which energy price increases are translated into product price increases. Since life-cycle costing involves a determination of future prices, this framework can be potentially useful to those making decisions that have consequences for future use of energy-intensive materials. Greater capital costs incurred as first costs may be economically justified based on the benefits associated with saving future maintenance that requires greater direct and indirect energy costs. One must carefully evaluate any design decision that implies a commitment to large use of materials for maintenance that will increase in price because of energy cost increases. The extent to which energy cost increases can translate into product price increases has just been shown. The regional variation among the various industries in their dependence on coal, oil, gas, and electricity has important implications for the

Table 1. Energy consumption distribution by industry and fuel.

Industry	Total Consumption[a] (10^{12} Btu)	Fuel (percent of total energy)				
		Oil[b]	Gas[c]	Coal	Electric[d]	Other[e]
Steel	3,031.0	8.0	20.0	62.3	4.4	5.4
Chemical	4,888.0	22.7	59.0	10.3	8.0	—
Petrochemical	3,854.0	26.6	60.1	7.1	6.2	—
Paper	2,130.0	22.0	21.0	12.0	5.0	41.0
Aluminum	586.0	11.0	37.0	1.0	51.0	—
Cement	514.0	15.0	43.0	35.0	7.0	—
Total	11,149.0	17.6	39.2	25.4	8.7	9.3

Note: 1 Btu = 1055 J.

[a] Data for steel, paper, aluminum, and cement correspond to 1973 consumption. Chemical and petrochemical estimates correspond to 1974.

[b] Includes fuel oil and oil-derived feed stocks.

[c] Includes natural gas and natural gas liquids.

[d] Electricity valued at its thermal equivalence of 3,412 Btu/kw·h.

[e] Nonmarketable fuels such as wood chips and pulping liquors.

Figure 1. Historical trends in energy/output coefficients.

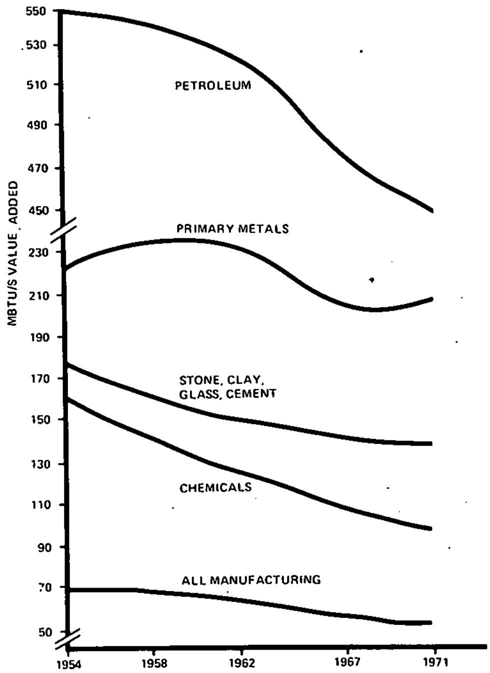

Table 2. Potential impact on nationwide fuel prices.

Fuel	Base Line	Case 1		Case 2	
		Amount	Percent	Amount	Percent
Coal	79.1	79.1	—	108.9	37.7
Oil[a]	195.4	258.1	32.1	258.1	32.1
Gas	52.4	95.4	82.1	96.4	82.1
Electricity	644.8	701.1	8.7	740.5	14.8

Note: Amounts are in cents/10^{12} Btu, where 1 Btu = 1055 J.

[a] Prices given correspond to residual oil.

Table 3. Estimated increase in average fuel costs.

Industry	Estimated Base-Line Prices[a] (dollars/10^{12} Btu)	Case 1: Tax and Deregulation Program (percent increase)	Case 2: Coal Price Rise (percent increase)
Steel	1.39	12.3	26.8
Chemical	1.37	42.7	44.2
Petrochemical	1.40	41.7	43.9
Paper	1.40	19.0	23.0
Aluminum	1.88	21.1	33.4
Cement	1.20	25.0	36.0
All	1.40	27.7	34.4

[a] Based on a mix of fuels given in Table 1 and price increases given in Table 2.

Table 4. Potential impact of fuel price increases on average output prices.

Industry	Absolute Fuel Price Increase (cents/10^{12} Btu)		Energy/Output Coefficient[a] (10^{12} Btu/dollars output)	Implied Increase in Product Prices (percent increase)	
	Case 1	Case 2		Case 1	Case 2
Steel	17.0	37.2	0.140	2.4	5.2
Chemical	58.5	60.6	0.072	4.2	4.4
Petrochemical	58.4	61.5	0.144	8.4	8.9
Paper	26.6	32.2	0.139	3.8	4.4
Aluminum	39.7	62.8	0.140	5.6	8.8
Cement	30.0	43.2	0.267	8.0	11.5

[a] Energy consumption relative to 1974 product prices.

product price increases likely to be facing roadway construction throughout the country. The declines in energy/output ratios shown in Figure 1 are expected to continue. Perhaps analogous to the "capital turnover" category of industrial energy conservation, this decline of E/O coefficients means that roadway construction and maintenance will be able to take advantage of the efficiency gains of industries that supply their materials and equipment. With energy prices increasing, these supplying industries can certainly be expected to economize on the use of more expensive energy inputs.

CONCLUSIONS

There are a number of reasons why optimal decisions concerning energy use are not made. Consideration of the true costs and benefits associated with each planning and design decision is not an easy task. Some of the reasons why energy costs are not always properly considered as a part of a life-cycle view of allocation of resources include

1. Incomplete knowledge of all costs and benefits associated with a certain project;
2. Uncertainty concerning future energy prices;
3. Desire to avoid the risk of trying new technologies and materials;
4. Institutional constraints in the form of specifications, materials, or construction methods (or all of these) that are unnecessarily stringent; and
5. Methods of funding roads that may emphasize minimization of first costs at expense of life-cycle and especially user costs.

Dealing with energy use requires a broad look at all of its implications. Narrow and traditional approaches are not appropriate when one deals with a resource whose price is increasing so rapidly and unpredictably. To even speak of the energy problems of the transportation sector or of the industrial sector as if they were separate is to adopt too narrow a view. An example may be helpful to illustrate this point. As noted earlier, roadways will be able to take advantage of the industrial sector's trend toward economizing on the use of energy per unit of output. One sector should not view the actions of the other sector as a "given." For example, in the case of specifications concerning blended cement, builders of roadways can help cement producers achieve reductions in energy use per unit of output. Use of blended cements should be evaluated carefully to see where they are and are not appropriate. A large market for this product can spur advances in the cement industry in the use of a proven energy-saving technology. There are undoubtedly many other areas where a better use of energy resources can be achieved through a broader view of energy use that does not compartmentalize a complicated problem.

REFERENCES

1. Impact of the Proposed Energy Deregulation/Tax Program on Five Energy-Intensive Industries. Office of Industrial Programs, Federal Energy Administration.
2. Energy Conservation in the Manufacturing Sector, 1954-1990. Task Force on Project Independence, Energy Conservation, Vol. 3.