Past and Future of the Petroleum Problem: The Increasing Need To Develop Alternative Transportation Fuels

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An examination of the interactions of petroleum supply and demand patterns suggests that the depletion of U.S. oil reserves and the increasing importance of oil consumption in U.S. transportation are causes for greater attention to the development of alternative (nonpetroleum-based) transportation fuels. Absent such development, the historical lessons presented in this paper suggest that another period of rising oil prices, erratic oil market behavior, and subsequent economic difficulty is probable within the next two decades. Methanol is argued to be the most likely and most desirable substitute transportation fuel because it can be produced more economically and used more efficiently than gasoline when derived from the rapidly expanding worldwide supplies of natural gas.

The basic argument of this paper is that it is imperative that the United States now devote increasing attention to developing substitutes for its petroleum-based transportation fuels. As Figure 1 shows, U.S. transportation now consumes more oil than is produced in the entire country. At the current level of oil prices, this situation is being exacerbated by a cutback in U.S. oil production and an increase in oil use in transportation. Contrary to popular opinion, the main cause of the post-1981 decline in oil prices and the recent oil price collapse is not increased fuel efficiency of vehicles. Instead, the primary cause is the adoption—in less than a decade—of substitutes for oil by electric utilities, industry, other businesses, and households. This conclusion is supported by data from Japan and Europe, as well as from the United States. Because transportation is using an increasing share of oil in the United States and other industrialized countries, the ability to successfully introduce substitute transportation fuels will be far more important when the next oil price run-up begins, possibly as early as the 1990s.

In the case of the 1973–1981 oil price run-up, prices were not driven down until transportation belatedly began to reduce oil consumption, reinforcing the consumption drop already under way in other sectors. History shows that substitution in transportation fuel in the United States has typically taken decades (*1*). If real oil prices are to be effectively capped below 1981 levels, the United States cannot risk waiting until after the start of another price run-up to begin introducing substitutes for petroleum in transportation.

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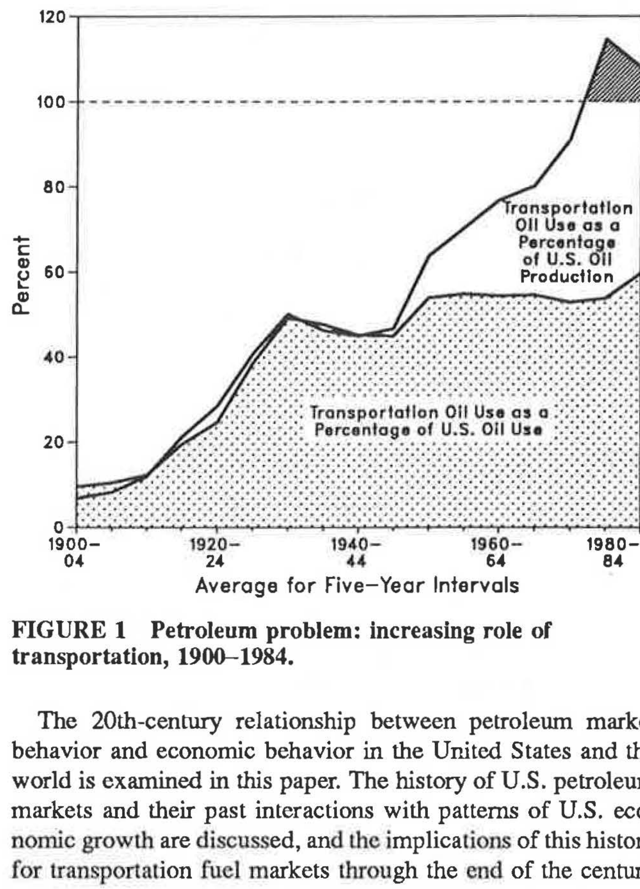

FIGURE 1 Petroleum problem: increasing role of transportation, 1900–1984.

The 20th-century relationship between petroleum market behavior and economic behavior in the United States and the world is examined in this paper. The history of U.S. petroleum markets and their past interactions with patterns of U.S. economic growth are discussed, and the implications of this history for transportation fuel markets through the end of the century are examined. More recent international trends in petroleum consumption and production are examined in detail, with special attention given to those multiyear periods when trends (i.e., growth rates) in domestic U.S. consumption and production temporarily diverge.

These periods are referred to as "gaps." Such gaps are shown to precede sharp oil price movements. The oil price movements themselves are associated with periods of relatively severe U.S. economic difficulties. Sharp oil price increases—"supply shocks" in macroeconomic terms—theoretically (*2–4*) and empirically (*5, 6*) are causes of recessions. Contrary to theory, 20th-century statistical evidence, and simple intuition, 19th- and 20th-century U.S. history does not indicate that energy price collapses cause economic booms (*1*). Thus both recent experience and longer looks at historical evidence indicate that sharp energy price movements are not desirable.

This paper and its supporting report (7) show that severe movements in petroleum price—both upward and downward—can be anticipated because they are preceded by a multiyear pronounced widening of the gaps just described. To reduce the severity of petroleum price swings, the gaps themselves logically must be reduced in magnitude. It is argued here that the petroleum market exhibits erratic price behavior because of difficulties in developing substitutes for oil. It is suggested that preparation of such substitutes must begin before price signals indicate the desirability of such preparation. If gaps can be "managed"—kept to a narrow range or substantially shortened in duration—the economy-wide consequences of subsequent wide swings in petroleum price should be avoidable. This, of course, is the same type of argument used by those who would have government intervene to reduce the inefficiencies of the business cycle (2). However, the argument is limited in the sense that it applies only to one sector of the economy and unique in the sense that wide gaps are early indicators of the need for policy action, allowing reasoned, careful development of policies designed to narrow the gaps.

THE "PETROLEUM PROBLEM"

The "petroleum problem" faced by the United States and its allies has two facets: (a) the economic exhaustion of petroleum and (b) the increasing dominance of petroleum consumption by the fuel-inflexible transportation sector.

Economic Exhaustion of Petroleum

Undeniably, the United States is running out of economically recoverable petroleum. Further, according to a statement attributed to OPEC President Rilwanu Lukman, it is a goal of OPEC to keep world oil prices low enough to discourage further development of Alaskan and North Sea reserves (*8*). In and of itself, this is not a theoretical problem. Many nations have maintained robust economic growth despite a lack of indigenous petroleum..Exhaustion of domestic U.S. petroleum does, however, mean that the United States will no longer be able to close consumption-excess growth gaps by increasing domestic petroleum production. Therefore the nation must rely increasingly on measures that

- Increase exports to earn the necessary foreign exchange to purchase imported oil, or
- Improve the thermodynamic efficiency of equipment that uses petroleum products, or
- Develop domestically produced substitutes for petroleum products, or
- Import substitute fuels that are less costly, or
- All of the preceding.

Increasing Dominance of Petroleum Consumption by the Fuel-Inflexible Transportation Sector

The ability of the United States and its allies to rapidly reduce consumption of petroleum products is diminishing because the transportation sector has increased its share of the industrialized nations' petroleum products consumption (Figures 1, 2) (*9–14*). Not only does transportation account for a historically high share of U.S. oil consumption, it also accounts for a far greater share of petroleum consumption than it does in competing industrialized nations (Figure 2). Further, among member nations of the Organisation for Economic Cooperation and Development (OECD), the United States is far and away the most dominant user of oil in transportation (Figure 3). This is a problem because each of the other petroleum-using sectors of the U.S. and other OECD economies managed to reduce petroleum consumption earlier and more rapidly than did the U.S. transportation sector after the two 1970s oil price shocks (Table 1) (*12*). In spite of legislation that mandated rapid gains in automotive fuel efficiency in the United States, the U.S. transportation sector had the least success in reducing petroleum consumption through 1985 (*10*). This pattern also held in Japan and Europe (*12, 14*).

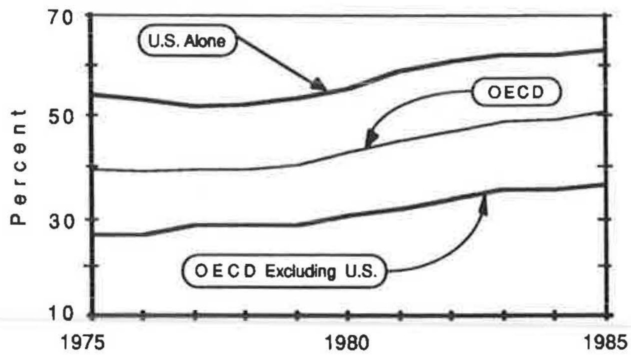

FIGURE 2 Shares of oil consumed by transportation in the United States and other OECD member nations, 1975–1985.

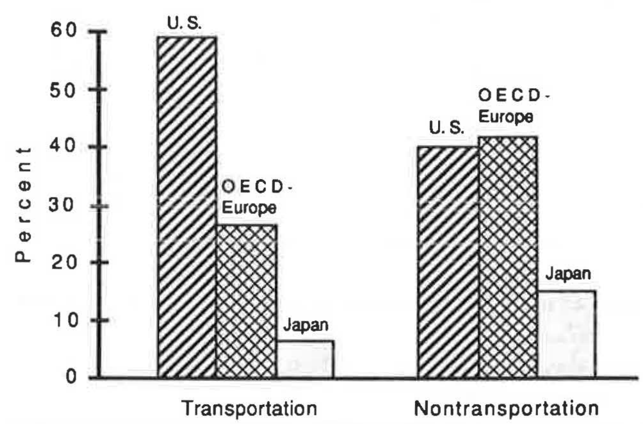

FIGURE 3 Shares of total OECD petroleum product consumption accounted for in 1981, by sector and location.

Oil Prices, Oil Imports, and Macroeconomic Activity

On another occasion in the United States (1915–1920), there was a doubling in real crude oil price during a period that was accompanied by increasing oil imports and immediately followed by a severe recession (*7, 13*). Although macroeconomic theory now recognizes the oil "supply shocks" as causes of recent recessions (*2–4*), very little reexamination of the role of such supply shocks as causes of pre–World War II recessions has taken place. In this paper it is assumed that if oil price

TABLE 1 PERCENTAGE DECLINE IN OIL CONSUMPTION FROM PEAK YEAR THROUGH 1981 FOR MAJOR OIL-CONSUMING LOCATIONS, BY SECTOR, POST-1978–1979 OIL PRICE SHOCK[a]

	Industry		Residential, Commercial, and Other Oil Consumers		Electric Utilities		Transportation		Overall	
Location	Decline	Peak Year	Decline	Peak Year	Decline	Peak Year	Decline	Peak Year	Decline	Peak Year
United States	23.1	1979	20.4	1977	43.4	1978	8.4	1978	13.3	1978
United Kingdom	28.5	1979	27.3	1979	50.8	1978	3.5	1980	16.6	1979
Federal Republic of Germany	21.5	1979	24.3	1979	35.6	1978	3.1	1980	18.2	1979
OECD-Europe	25.5	1979	16.3	1978	16.7	1978	1.6	1980	14.8	1978
Japan	28.4	1979	0.6	1980	25.8	1977	13.2	1979	22.2	1979

[a]For year in which oil consumption peaked through 1981.

shocks can be cited as causes of recent recessions in macroeconomics texts, other similar oil price shocks may also be assumed to have causally contributed to earlier U.S. recessions if statistical analysis supports such an assumption. Separate statistical analyses of the pre– and post–World War II periods do support this position (*5, 6*).

Thus, if a recession-inducing crude oil price increase (*6*) comparable to that of 1915–1920 or 1978–1981 [real price increases more than doubled in both cases (*7, 9, 13*)] occurred in the future, the United States, all other things being equal, would be less able to reduce oil import purchases and costs than in the past. The nation would also suffer more than its industrial competitors, who should have less difficulty reducing their oil consumption because the inflexibility of the transportation sector is relatively less of a problem for them (Figure 3). This appears to have been the case in the years immediately after the large 1978–1979 oil price jump, because Japan and Germany achieved greater immediate success than did the United States in reducing oil consumption (Table 1). Similarly, since the first oil price shock in 1973, total oil consumption as of 1986 had dropped by 19.1 percent in Japan, 17.7 percent in the Federal Republic of Germany, only 7.8 percent in the United States, and 16.5 percent elsewhere in the OECD (*14*). These declines in total oil consumption occurred in spite of an 11 percent increase in U.S. oil consumption in transportation from 1975 to 1985 and an even greater 23 percent increase during the same period in other OECD countries (*10, 14*)!

The purpose of this paper is to note and emphasize the possible importance of these facts in order to support the argument for the increasing need for well-conceived transportation strategies that can quickly reduce petroleum consumption. The paper is not intended to prove that the described energy-to-macroeconomy relationships are correct. It is intended to raise issues and provoke thinking about the importance of advance planning for quick introduction of oil substitutes when oil prices rise.

MANAGING THE NEXT GAP

Need in Transportation for a Petroleum Substitute

Introduction of substitute fuels in transportation will prove to be one of the most difficult transitions ever to occur within the U.S. economy. Because of their physical properties, petroleum-based fuels make ideal transportation fuels. Potential substitutes are costly and often inferior in key respects. Nevertheless, significant use of substitutes will eventually be needed, given the inevitable depletion of economical oil resources. Because the United States pioneered in the extensive use of oil in transportation (*11, 15*), it should logically be one of the first, if not the first, to face the need for developing a widely used substitute.

Methanol: A Possible Transportation Fuel Based on Natural Gas

Many current analysts consider methanol the most likely widespread substitute for petroleum-based gasoline (*15–22*). Methanol is a liquid fuel suitable for automobiles, and it can be made more cheaply from natural gas than can gasoline (*18*). Although recent worldwide discovery rates of crude oil have been disappointing, natural gas has been added relatively rapidly to world reserves (*9, 14*). Drilling for oil has taken oil companies to increasingly remote locations and greater depths. However, at greater depths the probability is higher that gas rather than oil will be found (*21*). Further, gas price increases of the 1970s caused increases in the search for natural gas for its own sake. Previously, most natural gas was an unwanted product associated with oil recovery. Recent changes in drilling patterns have resulted in far greater success in finding natural gas than oil. Since the oil price shock of 1973, world crude oil reserves have increased by 5 percent while gas reserves have increased by 93 percent (*14*). Thus, as oil becomes increasingly more difficult to find, the issue will be the kind of transportation fuel to make from the more readily available supplies of natural gas.

Automakers, the Environmental Protection Agency (EPA), the state of California, and numerous other entities are spending significant amounts of money on experiments to assess and improve the ability of U.S. automobiles to burn methanol cleanly and efficiently. The degree of success of these and other experiments and the timing of future market development efforts will have a major effect on when or whether the world and the United States experience another crude oil price run-up as high as those of 1915–1920 or 1978–1981.

SLOW PROCESS OF REVERSAL OF OIL PRICE INCREASES

Comparison of the 1915–1931 and 1968–1986 Oil Price Paths

The two worst 20th-century run-ups of crude oil price in the United States occurred in 1915–1920 and 1978–1981, after the two most prolonged and pronounced gaps in which growth rates of oil consumption exceeded those of domestic production. When these gaps were reversed and replaced by the 20th century's most prolonged and pronounced gaps of the opposite type, in which rates of production growth exceeded rates of consumption growth, oil prices were driven back down (Figure 4). This strong reversal of the consumption-versus-production-growth gaps was due in part to unusually severe declines in real national income, although energy conservation and fuel substitution also undoubtedly played a role.

Fifteen years after the steady real-price rise that began in 1915, oil prices plummeted to their 1915 level. In 1986, 13 years after a price rise that began in 1973, oil prices once more plummeted toward their preshock level (Figure 5). Dunkerley and Hoch (*23*) used international data to estimate that the price elasticity of "road transport" oil consumption is low (–0.2), but that income elasticity is high (+1.3); thus, the present

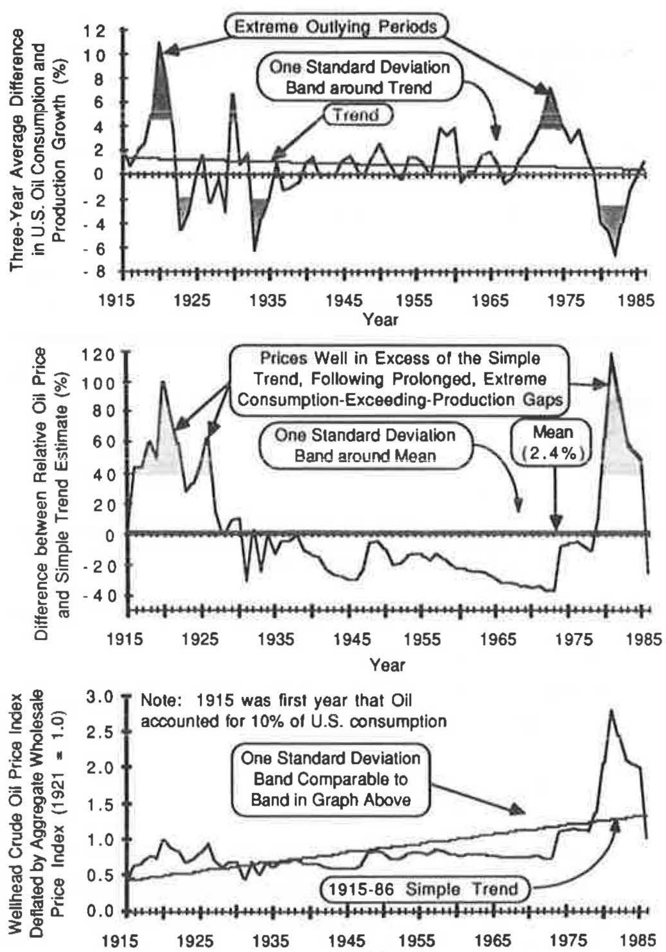

FIGURE 4 Movements of U.S. oil consumption-versus-production-growth gaps against real oil prices, 1915–1986.

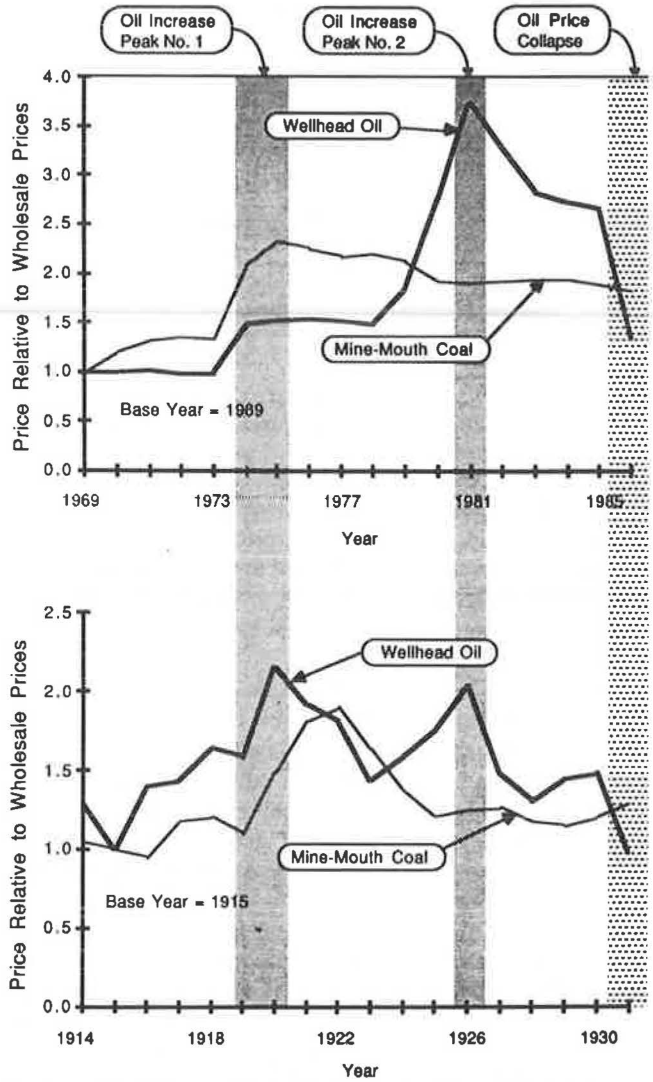

FIGURE 5 Long-term rise and fall of real oil prices: comparison of the 1915–1931 and 1973–1986 periods.

author infers that income losses in recessions and larger price responses in other sectors do more to drive oil prices back down than do price responses by the transportation sector. One major purpose of this paper is to decry this unfortunate inference and to argue, like Dunkerley, that actions to improve the price response are desirable if governments are to avoid using income losses to push down oil prices after price shocks (*23*).

That unusually severe U.S. recessions followed both of the worst U.S. real oil price run-ups implies that balance in the energy sector must be maintained if economic stability is to be achieved. If a prolonged and broad consumption–excess growth gap emerges, history implies that it must be balanced by another prolonged and broad gap in which growth rates of production exceed those of consumption. During the 20th century under the U.S. economic system, this has twice been accomplished by an initially sharp, and then prolonged, increase in real crude oil price that encouraged production, discouraged consumption, and—consistent with the "supply shock" theory (*2, 3*)—caused national output to be reduced far below the "natural" level. Consistent with the theoretical process of recovery from a supply shock, these combined effects

reversed the gap and depressed the crude oil price. On the first occasion (1915–1923), this process was followed by a period during which consumption and production were more or less in balance, and, aside from one mild recession, steady, robust economic growth (the Roaring Twenties) was experienced from the recession trough in 1921 until the end of the decade. In that case, the United States had the benefit of domestic oil discoveries but later paid the costs of writing down the value of those oil assets in 1931, during the collapse into the Great Depression.

On the first occasion, an initial sharp oil price run-up started in 1915 and was followed by a second oil price shock and subsequent collapse 15 years later. On the second occasion (1968–1986), not much new domestic oil was found after the first price shock, and a second shock, which was more severe than that of the mid-1920s, ensued. On this occasion, oil and transportation accounted for more of U.S. total energy consumption than in the 1915–1931 case, and the start-to-peak real oil price increase was greater (Figure 5). When oil prices collapsed in 1986, the absence of domestic discoveries was an advantage in that other nations carried a greater part of the burden of writing off oil assets. Nevertheless, recent events in the stock market raise the possibility that the process of writing off domestic oil assets may once again have contributed to financial difficulties in the banking system. Low oil prices have been reflected in low stock values for energy-center banks in particular, and the banking system in general, as well as record post–World War II bank failures. The oil market's behavior in 1916–1931 and 1968–1986 was similar in several respects. Both periods saw dramatic real oil price run-ups, with two distinctly different price shocks peaking 6 years apart. After the two price shocks, both periods witnessed prolonged and severe erosion of crude oil prices. In both cases, a collapse in crude oil prices occurred about 5 to 6 years after the second oil price shock (see Figure 5). Current events also imply that a rebound from the collapse, followed by another collapse, may also be a similarity of the two periods (see Figure 4).

A key finding of this analysis is that price movements within the petroleum market balance out (come to equilibrium), as basic economic theory would lead one to expect (*2, 3*). However, the process by which balance is reestablished (after a consumption–excess growth boom) has historically been quite long in duration and has involved recessions after the upward price movements. The analysis thus implies that the initial gaps themselves precede price shocks that cause subsequent declines in economic activity. When the gaps are created through declines in crude oil production, this sequence of events is consistent with "supply shock" textbook theory (*2, 3*). The widening of the gaps that precedes price shocks appears to be identifiable well in advance of the shock and the national income declines that follow (Figure 4). Given these characteristics, it would appear to be both possible and desirable to take steps to reduce the size of gaps before they contribute to the consequences identified here. Thus it is argued that the causes of gaps should be considered in advance so that the size of gaps can be limited (i.e., gaps should be "managed").

Statistical Evidence of Sectoral Responses to Oil Prices from 1973 to 1986

The descriptive examination of the 1915–1931 and 1968–1986 periods showed that a production-in-excess-of-consumption growth gap eventually drove real oil prices down in response to two prior large real oil price increases that were separated by about 6 years. Prices were not pushed back to the level that existed at the beginning of each period until this production-in-excess-of-consumption growth gap emerged. One question that arises from observation of this pattern of market behavior is "why was the initial price rise insufficient to cause enough substitution to drive the relative price back to its original level?" Although the emphasis here is on the relative difficulty of introducing substitutes for petroleum in transportation, it is also true that it is difficult, in an absolute sense, to introduce substitutes for petroleum in the short run in any major petroleum-using sector of the economy.

The process of substitution can be described as occurring in two phases logically separated by a few years. First, immediately after a price shock, consumers and investors substitute existing technologies to reduce oil consumption as much as possible. Some industrial and business consumers take advantage of a built-in ability to immediately switch fuels. In the second part of the substitution process, producers of energy-intensive products begin programs of research, development, and product introduction to implement new technologies that are more thermodynamically efficient or use more abundant, less expensive fuels, or both. The lag between the start of such programs and the first commercial sale of new products is typically several years. For example, flow charts (*24–26*) and public statements (*20*) by manufacturers indicate that 5 years are needed to complete engine development programs. If such lags also exist for furnaces, air conditioners, boilers, electric generators, and process equipment, it might be reasonable to expect a lagged reaction to sharp oil price increases after about half a decade. If this description of the substitution process is correct, then on those occasions when the first round of substitution—using existing products—is sufficient to push the price down to its original level, product development programs might well be shelved in favor of continuing production of existing technologies. However, if the initial substitution of other commercially available technologies does not push prices back down, a second price shock could be expected to cause commercial introduction of new technologies. If this is an accurate description of the process, the combined short- and long-term substitution responses to the pair of price shocks should be sufficient to push oil consumption below production and induce the needed price decline.

The problem with this sequence is that it implies that several years of sustained high prices must occur to cause the widespread adoption of new oil-substituting and oil-conserving technology. A. J. Sobey of General Motors has argued that it would take several years of gasoline prices well above recent levels to induce widespread substitution of methanol for gasoline (*16*). More recently, Sobey indicated that the process of substitution based on some low-cost non-U.S. gas sources could start at an oil price of $20 per barrel (*17*). If the process just described is accurately depicted, it is legitimate to expect the temporary but severe economic difficulties associated with petroleum price shocks to once more occur if large-scale development and implementation of oil-substituting technology in the transportation sector are not begun until after another substantial rise in oil prices.

To test for the existence of these effects and to statistically describe the nature of this process, the sector-specific short-

and long-run price elasticities of U.S. oil (and energy) consumption rates per unit of output for the 1973–1986 period were estimated using an individual, 13-observation, ordinary least squares regression model for each of the four major petroleum-consuming sectors, as categorized by the Energy Information Administration. The oil consumption data series that was used begins with 1973 (*10*). Annual oil consumption per unit of output was estimated by dividing sector-specific oil consumption by a measure of output for that sector. The output index for electric utilities was net generation (*10*), for industry it was the Federal Reserve Board industrial output index (*27*), for residential and commercial oil consumption it was constant dollar personal consumption expenditures (*28*), and for transportation it was vehicle miles of travel (VMT) (*29*). The advantage of measuring changes in energy use per unit of output is that the short-run elasticity estimates do not suffer from the upward bias (of the absolute magnitude of the negative elasticity estimate) resulting from the output losses that immediately follow an energy price shock. This short-run bias showed up in unreported regression models in which the author tested for its existence.

In the case of the residential/commercial sector, it was reasoned that the best measure of "output" would be a proxy for consumer utility, and real personal consumption expenditures were selected as the best proxy measure. In the case of transportation, the VMT series ended in 1985, so transportation estimates do not include the immediate response to the 1986 oil price collapse. A check of the effect of deleting 1986 in the other models of oil consumption showed no sign changes in otherwise significant variables, as well as consistently larger changes of elasticity estimates for short-run effects than for long-run effects. Changes in short-run elasticity estimates were -26 to +80 percent whereas changes in long-run estimates were -11 to +18 percent. The largest coefficient shifts occurred in the residential/commercial equation, in which the output index is most questionable in any case. On the whole, given the rather large differences in elasticity estimates across sectors, these experiments suggest that the transportation estimates can be reliably compared with those for the other sectors in spite of the exclusion of the "outlying" 1986 observation in the transportation model.

The rate of change of oil consumption per unit output (O_0), the rate of change of energy consumption per unit (E_0), and the rate of change of real crude oil price [(P_i), in 1967 dollars, from the American Petroleum Institute (*9*)], were computed by logging (using base 10) the ratio of this year's value to last year's value. Short-run elasticities were initially estimated by regressing this year's O- and E-values against present (P_0) and past oil price changes ($P_1, P_2, \ldots P_i$). Statistically significant price-induced reductions in O occurred immediately in the electric utility, industrial, and residential/commercial sectors, but not until the year after the oil shock for transportation (see Table 2).

After a lag of 1 year, statistically significant effects consistently disappeared in regression models with two or more P_i lags included. For comparability across all sectors, elasticities for contemporaneous reactions and for reactions after 1 year

TABLE 2 SECTORAL ESTIMATES OF SHORT-RUN AND LONG-RUN ELASTICITY OF OIL AND ENERGY CONSUMPTION PER UNIT OF OUTPUT WITH RESPECT TO OIL PRICE[a]

	Elasticity Estimates				
	Short Run				
Sector	P_0	P_1	2-Year Sum ($P_0 + P_1$)	Long Run (L)	Adjusted R^2
Oil					
Electricity	− 0.424	− 0.008	− 0.432	− 0.462	0.665
	(−3.71)[b]	(−0.05)		(−3.74)[b]	(8.91)[b]
Industrial	− 0.149	− 0.050	− 0.199	− 0.158	0.428
	(−2.69)[c]	(−0.66)		(−2.96)[b]	(3.97)[c]
Residential/	− 0.123	− 0.126	− 0.249	− 0.073	0.242
commercial	(−1.85)[c]	(−1.36)		(−1.22)	(2.27)
Transportation	− 0.010	− 0.042	− 0.052	− 0.045	0.677
	(−0.57)	(−2.58)[c]		(−3.21)[b]	(8.70)[b]
Energy					
Electricity	0.002	0.001	0.003	− 0.003	− 0.294[d]
	(0.22)	(0.05)		(−0.36)	(0.09)
Industrial	− 0.025	− 0.005	− 0.030	− 0.072	0.379
	(−1.07)	(−0.16)		(−3.14)[b]	(3.43)[c]
Residential/	≅ 0	≅ 0	≅ 0	− 0.023	− 0.065[d]
commercial	NE[e]	NE	NE	(−1.65)	(2.73)
Transportation	0.004	− 0.047	− 0.043	− 0.038	0.584
	(0.21)	(−2.48)[c]		(−2.31)[c]	(6.15)[c]

[a] t-statistics for coefficients are shown below the coefficient in parentheses; F-statistics for model R^2 are below the R^2 value in parentheses.
[b] Statistically significant at the 1 percent level (two-tail).
[c] Statistically significant at the 10 percent level (two-tail).
[d] A property of the small sample adjustment of the R^2 statistic is that a negative value can result from the adjustment.
[e] NE = Not estimated in the "best" model presented in the table; approximately zero in other estimated equations.

were estimated for every equation. For short-run elasticities, the remaining discussion refers to the sum of the P_0 and P_1 coefficients (elasticities) for the equation for each sector. These sums are given in Table 2, along with the separate P_i coefficients.

Long-run elasticities were estimated by an iterative procedure. The independent variable measuring long-run oil price pressure (L) used the log of the following quantity: oil price in a given year divided by oil price in an earlier year. The interval between the initial year and the earlier year was selected by examining R^2 improvements and coefficient t-values when the long-run variable was added to equations estimating short-run elasticities. Intervals as long as 7 and as short as 2 years were tested. The best interval proved to be 6 years. This interval was used throughout in the reported results. In addition to this iterative "optimization" procedure, the long-run price variable itself was lagged from 0 to 3 years (L_0, L_1, . . . L_3) and a "best" lag was determined, also based on R^2 improvements and coefficient t-values. These lags were 1 year each for electricity and transportation, 2 years for industry, and 3 years for residential/commercial. The elasticity coefficient for this long-run price variable indicates the longer-run effect of a quasi-permanent price increase, rather than the short-run shock effect indicated by the P-coefficients. Other long-term lag formulations, such as distributed lags, have not been tested at this time. Results of these experiments are given in Table 2. Each regression model included a constant term, which is not reported. Short- and long-run elasticity estimates by sector are shown in Figure 6. The degree to which substitution versus straight conservation is responsible for reduced oil consumption in a given sector can be approximated by comparing short- and long-run elasticities for total energy consumption with those for oil-derived energy consumption. The ratio of the oil price elasticity of total energy consumption to that for oil energy consumption (times 100) approximates the percentage of the oil-energy-per-unit-of-output (O) reduction achieved by conservation. Subtracting this quantity from 100 approximates the percentage achieved through substitution. The results of this latter substitution share approximation are shown at the bottom of Figure 6, directly under the elasticity values from which they were derived.

The numbers of observations in these regressions are relatively small—smaller than those found in statistical tables for the Durbin-Watson d-statistic. On the basis of linear extrapolation of the d-values, application of the Durbin-Watson test (results not reported) did not allow conclusive determination of the presence or absence of autocorrelation. Because of the small number of observations, the R^2 value presented is the adjusted value *(30)*.

The statistical results of these experiments tend to confirm the present descriptive analysis of the relative difficulty of substituting for oil in transportation. The estimates for both short- and long-run elasticity for transportation are substantially smaller in absolute magnitude than for the other sectors (Table 2 and Figure 6). Further, supporting the earlier descriptive arguments, the percentage of reduction in oil use estimated to have occurred through fuel substitution is far lower for transportation than for any other sector (Figure 6). These results also support the argument that there is a quite long lagged technological response to sustained energy price increases,

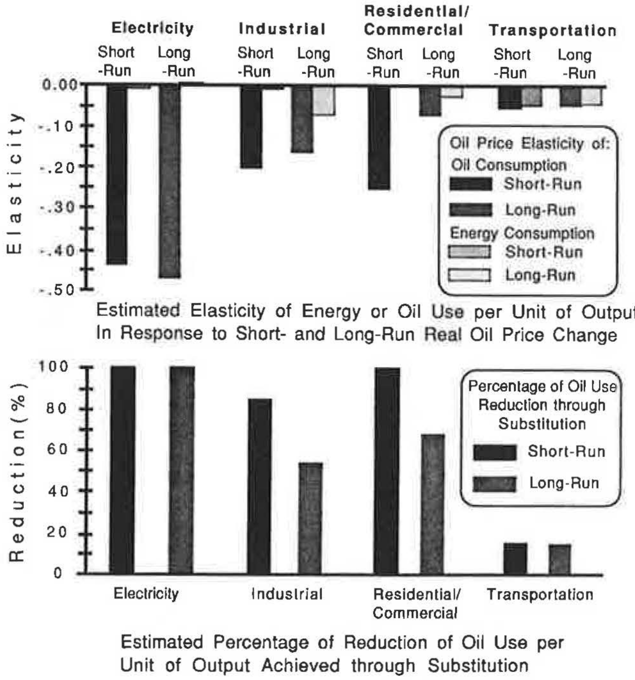

FIGURE 6 Sectoral estimates of short- and long-run elasticity of oil and energy consumption in response to real oil price: comparison with estimates of substitutability for oil, 1973–1986.

which takes hold only after years of effort to research, develop, and introduce new and improved energy conversion technologies.

LONG-TERM LIMITATIONS OF U.S. OIL SUPPLIES

A fundamental problem faced by the United States is the declining domestic supply of economically recoverable oil (Figure 7). Since 1900, the growth rates of oil consumption and production have moved in a clear, although slightly erratic,

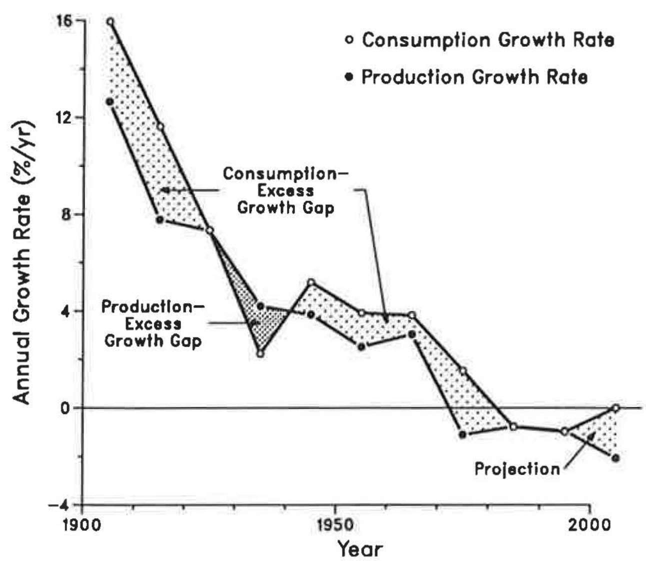

FIGURE 7 Decade averages of oil consumption and production growth rates (history to 1980, projections to 2005).

downward path. Ominously, in the 1970s, domestic U.S. production "growth" rates turned negative. Although consumption growth rates have not declined as rapidly as production growth rates, it is clear that consumption growth rates have steadily declined in concert with domestic production limitations. The unsteady reduction of consumption growth rates until they shifted into decline in the early 1980s was promoted by unsteady but clear long-term increases in oil price relative to prices of other goods (Figure 4). Domestic production of oil is clearly constrained by cost. The unprecedented price increases of crude oil of the 1970s only reduced the rate of decline of domestic production; they did not lead to an actual increase in domestic production. Rates of consumption growth, however, were turned into declines even greater than those in production. Thus the production–excess growth gap of the early 1980s was far different than that of the early 1930s (Figures 4 and 7).

Because growth rates of oil consumption were consistently above those of production during 1945–1978 (Figure 4), imports were needed to make up the difference (Figure 8). On average, the difference between consumption growth and production growth was relatively steady and slight during 1950–1968 (Figures 4 and 9), leading to a slow increase in the gross percentage of imported oil from about 13 to 21 percent. The United States found that imported oil was cheap, and thus it maintained trade surpluses throughout the period; through 1968 this trend was readily manageable. Given the growth trends of oil price and domestic consumption and production for the period, this pattern probably could have continued for many years.

CAUSES OF THE RECENT GAP

Regulations

The steady trend of 1950–1968 did not continue. Legislation was passed to improve safety in underground coal mines, most of which were in high-sulfur eastern coal fields. At the same time, sulfur dioxide emissions standards for power plants and industry were legislated and promulgated. The result was a sharp increase in the cost of burning the dominant coal (i.e., high-sulfur eastern bituminous). This was reflected in a coal price shock during 1968–1971. Consistent with supply shock theory, a recession occurred in 1970. Unable to burn coal cleanly and economically under the new regulations, electric utilities and industry began a massive switch to oil during 1968–1972 (Figure 10). This led to an average increase of more than 1 percent per year in the growth rate of oil consumption during 1968–1973.

Absence of Transportation Influences

The recent gap was not, contrary to popular opinion, created by events in the transportation sector, where the growth rate of oil consumption actually dropped below the 1950–1968 average (Figure 10). This gap led to a sharp increase in the need for, and the use of, imported oil (Figure 8)—especially from the Middle East—making the United States highly susceptible to the imposition of an oil embargo. The ensuing crude oil price rise (Figure 4) cannot, according to the logic of this paper, be attributed to anything other than the U.S. gap, given the absence of such a gap worldwide (Figure 9).

Oil Production

Production of U.S. oil peaked during 1968–1973 just as consumption growth began its regulation-induced increase. The combination of increasing consumption growth and decreasing production growth created a severe consumption–excess growth gap in the United States (Figure 9) at the same time that free-world consumption growth rates were actually below production growth rates.

Oil Imports

When growth of oil consumption exceeds that of domestic oil production for a period of years, it is obvious that the extra oil

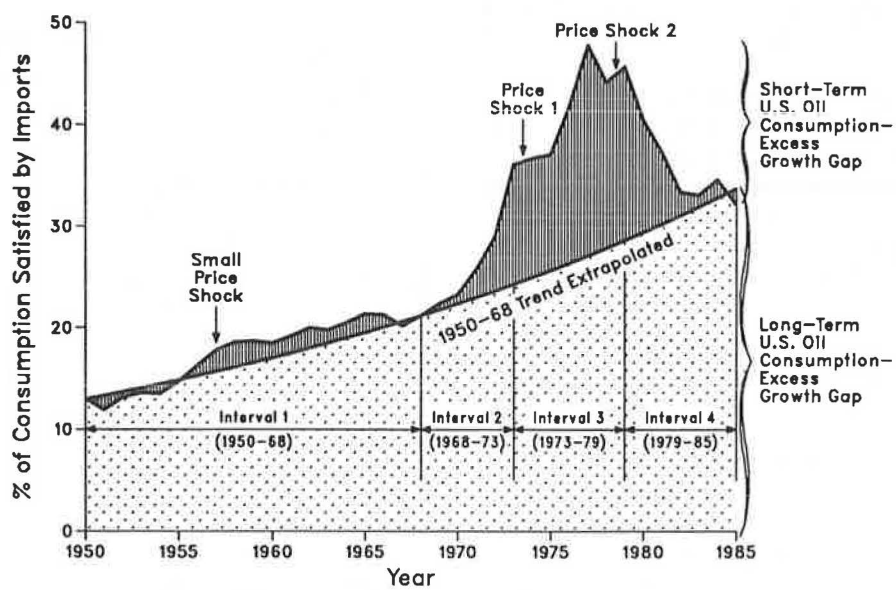

FIGURE 8 Short- and long-term patterns of gross oil import shares in domestic U.S. oil consumption, 1950–1984.

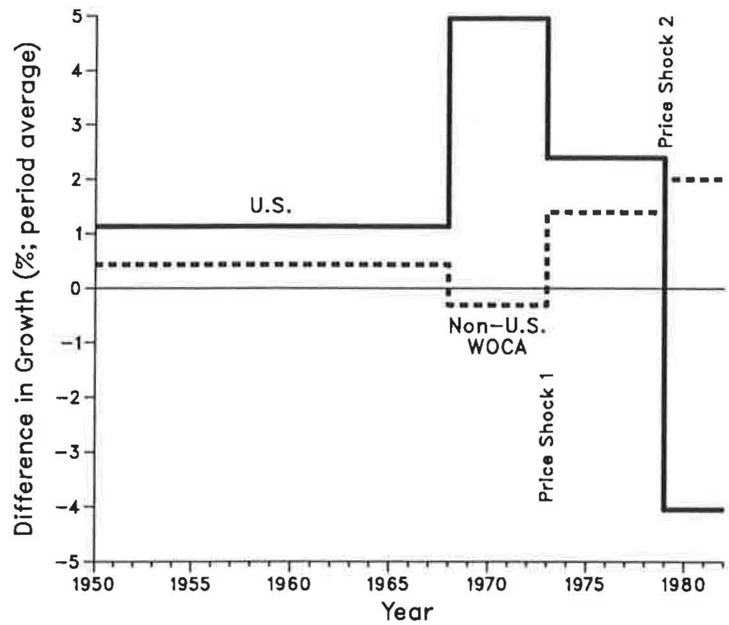

FIGURE 9 Difference between growth rates of oil consumption and production for United States and world outside communist areas (WOCA), 1950–1982 (period averages).

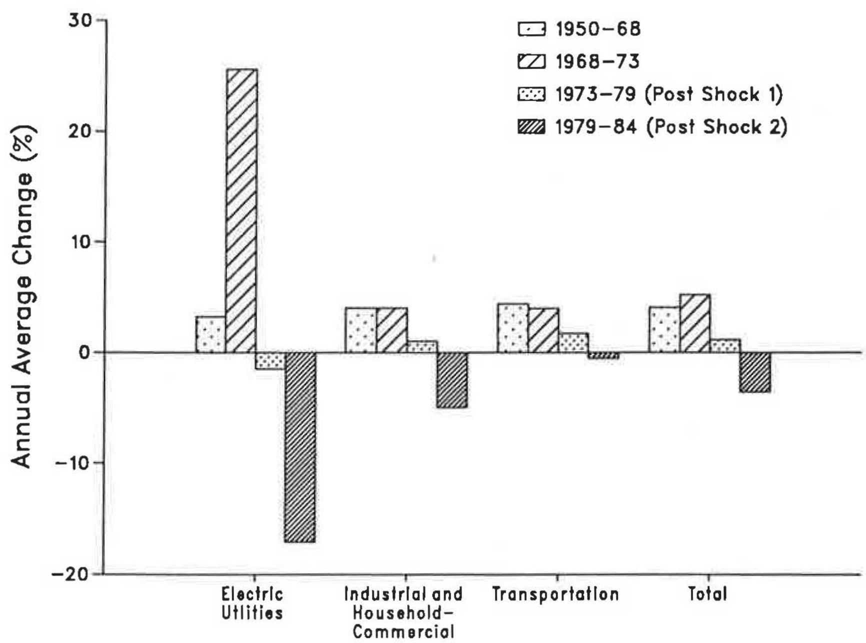

FIGURE 10 Changes in sectoral rates of growth of oil consumption, 1950–1984 (period averages).

must come from elsewhere. Importing oil allows the gap to emerge, but it also makes the U.S. oil supply and economy more susceptible to events beyond its borders. Each of the most severe U.S. oil price run-ups in the 20th century occurred when oil import percentages were at all-time highs (Figure 11). It appears that in both cases the market decided that the increasing dependence on imports had to be reversed, because the ensuing oil price increases led to subsequent sharp drops in the percentage of imported oil.

INCREASING NEED TO DEVELOP OIL SUBSTITUTES IN TRANSPORTATION

Role of Transportation in Overall Oil Consumption

As mentioned, transportation was less responsible for initiating the 1968–1979 gap than were other sectors (Figure 10). Although the other sectors did increase their oil consumption during 1968–1973, they were able to rapidly reverse these

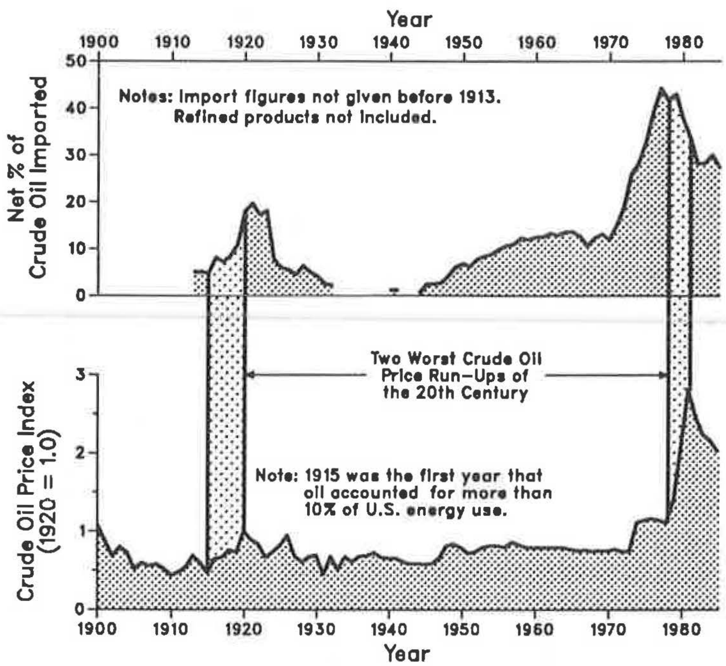

FIGURE 11 Comparison of net percentages of imported crude oil with a crude oil price index, 1913–1982.

increases so that they contributed far more to the closure and reversal of the gap than did transportation. This was possible mainly because it was far easier for these sectors to switch fuels than it was for transportation. Indeed, transportation's growth momentum and its inflexibility in fuel substitution and conservation caused this sector to consume more oil in 1985 than in 1973, while each of the other sectors reduced oil consumption enough to cause an overall decrease in consumption (Figure 12).

The long-term pattern in which transportation captures an increasingly large share of the petroleum products market continues unabated in the United States and other industrialized nations (Figures 1 and 2). These nations can therefore expect the inflexibility of transportation to be an even greater problem during the next gap. Further, because the United States has been relatively successful in finding substitutes for oil in nontransportation sectors, it uses a far larger share of its petroleum products for transportation than do its industrial competitors (Figure 2). Thus the United States has been, and will continue to be, less able to quickly reduce its oil consumption in response to a price shock than have been, and will be, its industrialized competitors.

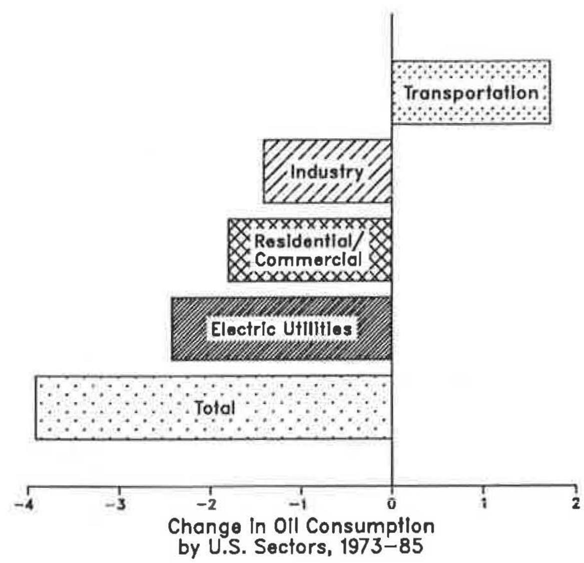

FIGURE 12 U.S. sectoral changes in oil consumed per year, 1985 versus 1973 (in quads; 1 quad = quadrillion, or 10^{15}, Btu).

Summary of Basic Arguments

The fundamental arguments of this paper can be summarized as follows:

- Because of its inability to economically and rapidly substitute nonpetroleum fuels (Figure 6), transportation historically has been less able to reduce petroleum consumption than have other sectors of industrialized economies (Figures 1 and 2).
- Because of transportation's fuel inflexibility, industrialized nations that devoted a greater share of their total petroleum consumption to transportation had greater difficulty reducing oil consumption after the 1978–1981 crude oil price run-up (Table 1).
- The United States devotes a far larger share of its petroleum consumption to transportation than do its industrial competitors (Figure 2).
- The United States is by far the most dominant transportation oil consumer among OECD nations, accounting for nearly 60 percent of all OECD consumption (Figure 3).
- The long- and short-term evidence indicates that the trend in the United States is toward use of a greater share of petroleum products by transportation (Figure 1).

• The short-term evidence indicates that other industrialized OECD nations are also devoting increasing shares of their petroleum consumption to transportation (Figure 2).

It is therefore clear that when the next oil consumption–excess growth gap appears likely, the success or failure of U.S. efforts to reduce consumption by transportation will be more important than ever before in preventing or reversing the gap. Because the success of such efforts in other sectors has been greatly enhanced by those sectors' ability to substitute nonpetroleum-based fuels, logic suggests that this capability must be developed in transportation if even more calamitous economic consequences than those of the early 1980s are to be avoided.

Need for Gradual Introduction of a Petroleum Substitute

The problems with developing a substitute fuel for transportation are the high cost and the great amount of time needed. If it were not for the high cost, the price run-ups of the 1970s would undoubtedly have brought on the widespread introduction of substitute fuels in transportation. Because many years are needed to smoothly implement new and more costly transportation fuel technologies (witness the slow phase-in of unleaded gasoline)—whereas crude oil price run-ups occur in only a few years or even a single year—the free market cannot respond "efficiently" to crude oil price signals. Consequently, enlightened nonmarket intervention in the transportation fuels marketplace will be necessary if yet another severe price run-up and recession are to be avoided. The key word here is "enlightened," because intervention in the fuels marketplace is the rule rather than the exception. The influence of environmental and safety legislation on fuels markets is as old as the markets themselves. Earlier intervention, however, more often contributed to the creation of gaps than to their elimination [see Santini (*1*) for a detailed discussion of regulatory influence on fuel markets].

Relatively rapid fuel substitution in U.S. transportation has occurred several times, but never within a period of only a few years. Typically, substitution accelerates during a time of unusually depressed business activity. Major transportation fuel shifts occurred in the late 1830s and early 1840s, the 1870s, the 1890s, and the 1920–1940 period (*1*). A U.S. depression of several years occurred during each of these periods (*1*). If the transition from leaded to unleaded gasoline was not major, then no major shift occurred in 1970–1985, but, as has been seen, the need for a major shift becomes ever more pronounced as transportation increases its share of petroleum products use and as the United States and ultimately the world run out of economically recoverable oil.

Methanol: A Possible Mass-Market Substitute Fuel

As the world runs out of oil, both long-term and recent history suggest that natural gas will be the most common source of substitute transportation fuels (*16, 17, 31*). From 1973 to 1987, gas reserves in noncommunist countries increased by 67 percent, while reserves of free-world oil increased by only 9 percent (*14*). Long-term trends show gas capturing an ever-increasing share of the fuels market. Natural gas was originally found in unwanted association with crude oil and still is often flared at the well or reinjected into the field because of the lack of a market. Because crude oil relatively near the surface has been depleted, many deeper wells drilled to find oil have found gas instead. At greater depths, gas is more likely to be found than is crude oil (*21*). Thus, as oil reserves are depleted, a greater proportion of gas is found. Further, recent high prices for natural gas led to more searches for gas for its own sake.

Although natural gas can serve as a source of gasoline, it is a more cost-effective source of methanol (*18*). (Both gasoline and methanol can also be produced from coal, but, again, methanol would be the cheaper of the two—although more costly than methanol from natural gas.) Thus a switch from gasoline to methanol would pay dividends to the United States for many decades because coal derivatives are likely to be the transportation fuels of the far future, following (and overlapping) the era of natural gas. Although gasoline or a gasolinelike fuel might be produced from natural gas, a large body of research is emerging in favor of methanol on both cost and environmental grounds (*17, 18, 32*).

Methanol can be burned "neat" (pure) or "near-neat" in a vehicle specially modified for the purpose. It contains less energy per gallon than does gasoline, but a properly designed engine can burn it with greater thermodynamic efficiency. Thus a methanol-powered vehicle designed to provide the same horsepower per pound as a gasoline- or diesel-powered vehicle would have a larger fuel tank but a smaller engine. The use of neat or near-neat methanol has the potential, according to current EPA research, of reducing smog in urban areas, an environmental goal that is proving difficult to achieve (*32*). One difficulty with near-neat methanol is its poor cold-start properties in current vehicle designs. This problem has been addressed in Canada by government-sponsored research and is now being investigated more aggressively in the United States.

Methanol could be gradually introduced into the gasoline market because of its ability to boost the octane of gasoline; indeed, this is now being done by some refiners because of federal requirements to remove lead from gasoline. Although methanol is still too expensive to burn as a neat fuel, it has a much higher dollar value than gasoline when used as an octane booster. Among octane boosters that can replace the cheap but environmentally unacceptable tetraethyl lead, methanol is quite cheap (*33*). Used this way, however, methanol does not have the desirable environmental properties that it has as a neat fuel; thus, from an environmental standpoint, its ultimate use as a near-neat fuel remains desirable (*32*). Materials problems, such as corrosion, related to use of methanol blends have largely been solved by automobile manufacturers, but many existing vehicles could experience materials-related problems if they used methanol blends.

Other Possible Substitutes

Although it is the judgment of this author that methanol is the universal fuel of the far future, other fuel substitutes are possible, especially for selected market niches. Compressed natural gas, liquefied natural gas, liquid propane, ethanol, and "synthetic" fuels made from coal, oil shale, and tar sands are all technically suitable and occasionally economical transportation fuels under specific, limited market conditions. It must be

stressed that small changes in fuel supply can make large differences in fuel prices, so even small substitutions of fuels other than those based on crude oil can have a strong effect in holding down crude oil prices. Given current cost estimates, however, these fuels are far less likely than methanol to serve satisfactorily as a universal, internationally traded, inexpensive standard fuel.

Questions of Timing and Effort Level

Given the ultimate need for an oil substitute in transportation, questions remain about probable timing and effort levels of needed government and industry research and development (R&D), government regulation, and industry investment and marketing. Most leading forecasters project an acceleration of crude oil prices in the 1990s, although they differ on the degree of increase (*34*). Even the Atlantic Richfield Corporation (ARCO), which anticipated sharp declines in real oil prices in three of its four publicly released strategic planning scenarios, projects rising real crude oil prices in the 1990s in each of those cases (Figure 13) (*35*). Unlike recent projections for the United States by the U.S. Department of Energy (DOE), however, these projections assume a "cap" on future oil prices below the 1981 level. ARCO has more experience with methanol than any other major oil company and assumed that a methanollike fuel would cap oil prices. Chevron published far higher cost estimates but nevertheless calculated that the price of methanol would be lower than some of DOE's earlier projected oil prices (*36*). A. J. Sobey of General Motors has cited the lowest cost, quoting $20 per barrel of oil "equivalent" from some non-U.S. sources of natural gas (*17*). Presumably, one difference between the ARCO and Chevron projections is the assumed amount of cost-cutting innovation that can be expected in future methanol production. The Sobey $20 estimate relies on quite low wellhead gas costs and on nearby sources. Recent cost estimates and levels of R&D effort imply that cost-cutting innovation may be rapid (*17, 37, 38*).

In one Data Resources, Inc. (DRI) projection and in two 1984–1985 DOE projections, the costs of petroleum-related imports (products and crude) in the late 1990s or early 21st century exceed the value of the worst U.S. trade deficit in history (1986), as well as that of the worst U.S. oil trade deficit in history (1980) (*7*). These projections were of interest because they illustrated the U.S. dilemma that can be expected because of the inevitable decline in oil output. If the United States is to reduce its oil use and oil imports, the price of oil must rise dramatically—thus causing its oil import bill to rise. If the United States has the benefit of low-cost oil imports, it will produce less domestically and increase its imports dramatically—thus causing its oil import bill to rise.

Methanol could reduce the seriousness of this situation in two ways. If methanol were produced from indigenous natural gas sources (more probable with high prices for world crude), import costs would be lowered largely by reducing import quantity. If methanol were provided through imports from low-cost international suppliers, it could reduce total transportation fuel import costs by holding down the price of imported fuel. The ability to readily substitute methanol for gasoline is necessary to achieve the price restraining effect. Both of these positive effects could be put into place with a carefully crafted methanol transition strategy developed through cooperating industrial and government organizations. The most optimistic (lowest oil price, highest economic growth) scenario considered by ARCO ("economic renaissance") apparently assumed such a transition. ARCO assumed, among other things,

- "[A] long-term view,
- "Major successes with . . . alternative energy, and
- "Practical energy and physical environment policies."

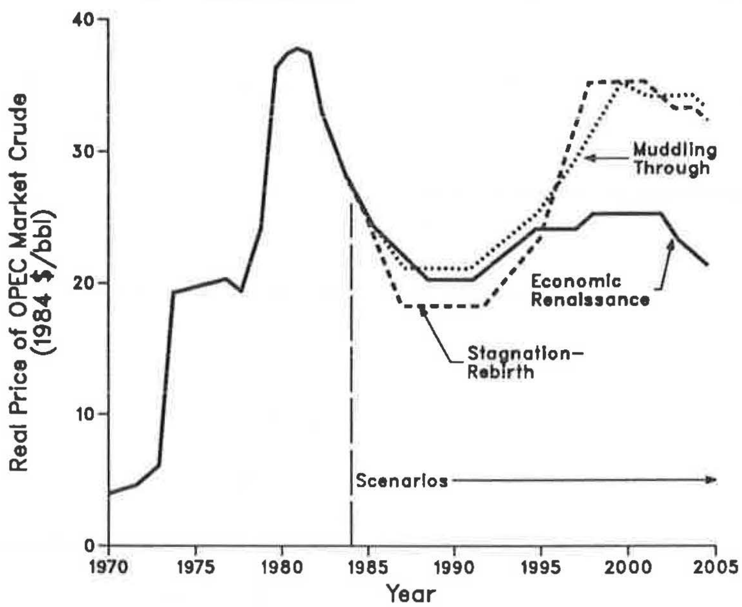

FIGURE 13 Three of four published ARCO 1985–2000 oil price scenarios developed for strategic planning.

Given the consensus of experts on pressures for an oil price rise in the 1990s, "long term" for the petroleum problem may well be less than a decade. Given the lessons of history and the results given in Table 2 and Figures 4–6, preventing a severe oil price run-up by developing substitute transportation fuels will take several years at best. In this paper, it is argued that the time to develop substitutes is when the gap becomes severe. Thus the time to accelerate efforts to develop such substitutes (counterintuitively, given recent declines in oil prices) is now. If early 1987 trends in U.S. oil consumption and production are indicative of the full year's behavior, 1987 will have been a year during which the United States once more opened up an "extreme, outlying" consumption-in-excess-of-production gap as defined in the topmost portion of Figure 4. If 1988 becomes what 1987 was, the gap in 1988 will be as large as it was at its peak in the 1970s. If this gap remains wide, a sharp oil price rise in the 1990s is quite likely indeed.

CONCLUSIONS

It has been argued, by examining petroleum market characteristics for the first 85 years of the century, that a long-term view, in which practical energy and physical environment policies are followed to achieve major successes with alternative energy, is crucial if the goals of steady economic growth and competitive success in the international marketplace are to be ensured for the United States through the rest of the 20th century. It has been shown that if these goals are to be met, a far greater emphasis must be placed on introducing alternatives to petroleum in the transportation sector.

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