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The Oil Market in the 1980's: Challenges for a New Era
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Drill Rigs and Battleships Are the Answer! (But What Was the Question?)

Oil Efficiency, Economic Rationality, and Security

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Cyclical concern about U.S. oil depletion has for many years drawn forth almost every kind of reasoned or tendentious argument save one: serious exploration of a *least-cost oil strategy* based on pursuing the best buys first.[2] Just as no corporation can long survive in the marketplace unless it uses its resources economically, so no nation, however richly endowed, can long remain secure and competitive if its energy strategy ignores the market's cost-minimizing imperative. Today's oil problems are a harbinger of the far more severe ones that will arise if costly options continue to be pursued to the virtual exclusion of cheap ones.

US. oil policy has long emphasized depleting oil reserves in the United States first, other regions later, and oil-rich parts of the Middle East much later. Three responses are available to the resulting depletion of cheap domestic oil:[3] protectionism, trade, and substitution. Protectionism, and the various policy options subsumed under trade (friendly relations, diversification, stockpiling, military force), seek to mitigate some of the consequences of depleting different provinces at different times. Neither protectionism nor trade, however, seeks to slow domestic depletion or to provide replacement supplies. Paradoxically, many proposed "strength-through-exhaustion"[4] policies, which could be classified under protectionism, respond to domestic depletion only by accelerating it.

In contrast, substitution would gradually replace oil by a judicious combination of more efficient use and alternative fuels. Only substitution looks beyond the petroleum era. Only substitution can avoid the serious problems inherent now in protectionism and later, if not now, in largescale oil imports. And substitution–of higher oil productivity for burning oil itself–is, we shall suggest, at the core of an energy policy that takes economics seriously.

This chapter examines how the efficient use of energy, particularly of oil, can help to create and smooth a transition beyond oil. It analyzes the dynamics of how the United States used efficiency to improve its oil supply/demand balance throughout the period 1977-1985. It also explains the unusual events that in 1986 reversed this steady decline in oil imports. Finally, it quantifies the approximate size and cost of the least-cost technical and policy options available to reduce or eliminate oil imports while stretching domestic resources in the years and decades ahead.

Lopsided Policy Emphasis

Misdirected emphasis on supply expansions is now becoming not only wasteful but also dangerous. As will be shown, cheap oil-saving opportunities offer practical, presently available ways to run today's U.S. economy with about a fourth as much oil as now, at an average cost of savings probably under $10 per barrel–far less than the finding cost of new domestic oil. Despite this, official policies continue to emphasize supply options that cost about *ten to a hundred times* more than readily achievable, less risky ways to save oil through more efficient use. The Reagan administration's military intervention in the Gulf, for example, increased the effective cost of imports from that region (neglecting all the military risks involved) to a FY1985 level of about $495 per barrel– eighteen times as much for the military force as for the oil itself.[5] Yet the same administration rolled back auto-efficiency standards whose societal marginal cost, if it exceeds zero,[6] is at most a few dollars per barrel saved. Those U.S. new car standards alone–one of the most effective oil-saving programs the world has ever seen–accounted for a fifth of *all* oil saved (6.2 MMB/D) during 1979-1983 by the twenty-one IEAnations.[7] Rolling them back starting with 1986 cars is shown below to have doubled 1985 U.S. imports from the Gulf.

The asymmetry between supply and efficiency initiatives continues to dominate public policy and many private-sector attitudes. After the oil crises of 1973-1974 and 1979-1980, the federal government sought to spur supply with public subsidies and removal of procedural or environmental constraints.[8] Both times, however, those efforts collapsed and the overbuilt supply industries faced insolvency as the market instead produced a largely unforeseen gush of efficiency. The Reagan administration seems to have been determined to make this mistake a third time.[9]

Many policymakers continue to be slow to learn that energy demand is not fate but choice, an enormously flexible choice. Customers can and do buy energy-saving devices at need. This flexibility is often overlooked, in part because efficiency options are less familiar and come less readily to mind than supply options. Insulation installed out of sight and out of mind in millions of attics is somehow less impressive than one huge power plant, even though the insulation provides larger, cheaper, and more reliable energy services. The striking successes of efficiency are less well known than the more limited successes of supply expansions, are not promoted by lavish public relations campaigns, and hence are given less credence. The risks and uncertainties of supply versus demand options are seldom compared fairly and symmetrically. This chapter, by sketching basic elements of the "supply curve" of available oil savings, seeks to make efficiency easier to discuss on the same footing as supply.

Implications for the Oil Industry

Most thoughtful oil analysts now foresee fairly flat long-term real oil price trajectories. In these circumstances, upstream rents are scarce. Downstream rents were long ago squeezed out. The only big rents left to be captured are the spread between the cost of extracting barrels and the cost of savin*g* barrels, which might be called "producing 'negabarrels.'"[10] (This rent represents the difference between the supply curves of extracting oil and those of saving oil.) An oil company wishing to stay competitive should consider selling a mix of barrels and negabarrels, altering their proportions to suit current market conditions.

This strategy offers important advantages. For example, when real oil prices fluctuate unpredictably–as many analysts believe they will for at least the rest of the twentieth century[11]–between, say, $15 and $25 a barrel (with odd spikes now and then as war or peace breaks out in the Middle East), smart oil companies will find that it is much easier to make their margins selling negabarrels that cost $5 to produce than barrels that cost $15. To be sure, the mix of oil and efficiency that one sells can and should vary with current market conditions; but including in that mix a hefty dose of efficiency yields cheaper energy services–a better buy for the customer–and virtually eliminates downside price risks. (Avoidance of other kinds of risks is discussed at the end of this chapter.)

Saving oil, too, does not just stretch supplies further and hold down prices, as it did so dramatically in 1986; it also helps to bring sorely needed stability to world energy markets. The basic reason that prices fluctuate for oil, as for copper, wheat, and sowbellies, is that consumers' and suppliers' response to surplus or scarcity is not instantaneous: It is delayed by lags of both perception and logistics. Even *if* politics did not affect oil prices at all, lagged responses by buyers and sellers would still make prices volatile, like a driver who reacts too late and oversteers a car. Amid short-term price fluctuations, however, two "slow variables" are also operating: depletion, which raises the price, and more efficient use, which lowers the price. If depletion proceeds faster than efficiency, price will become more volatile. But if efficiency proceeds faster than depletion, it will tend to dampen price volatility, moving long-term markets toward stability and predictability. That is certainly in the interest of any capital-intensive business such as the oil industry.

For any oil company wishing to survive, paying careful attention to oil-saving opportunities is not a luxury but a necessity. The world is already irreversibly in an era of relatively costlier fuel and cheaper efficiency. Customers will increasingly want to get their energy services by buying less fuel and more efficiency. Energy companies that sell them that altered mix will prosper; those that only seek access to ever-costlier oil will falter.

Since before the first oil shock, such success as we have had in foreseeing the evolution of energy markets has come from careful attention to economics, from faith that, given the choice, customers will seek the best buys in each end-use. The energy industries can choose to aid or inhibit the spread of efficient energy use, to embrace or ignore, facilitate or stall, the flowering of the energy service marketplace. But in the long run, their choice is only between participation in the efficiency revolution and obsolescence. Efficiency options are increasingly available and will sooner or later be bought, with or without fuel vendors' foresight, blessing, and participation. The only choice is who will make money on efficiency, and who will use it cannily to hedge against the remaining, much reduced, risks in the ever less dominant supply-side markets.

Oil Savings Achieved

Virtually unnoticed, efficiency improvements have outperformed all efforts to expand energy supplies. It is vital to understand how and why this occurred. The United States in 1987 used a third less oil to produce a dollar of real GNP than it did in 1973. A minor part of this reduction was due to small changes in behavior. The average U.S. passenger car was driven 6 percent fewer miles in 1986 than in 1973, despite 4.5 percent lower real gasoline prices;[12] surprisingly, only 4 percent of the 1976-1987 gain in car-fleet efficiency was the result of shifts to smaller cars.[13] Probably more of the reduction was due to changes in the composition of economic output (less steel[14] and cement, more computers and financial instruments). The majority of the savings– by most estimates more than three-fourths–was due to technical gains in energy productivity. These gains came chiefly from such mundane measures as caulk guns, duct tape, plugging industrial steam leaks, and modestly raising car efficiencies.

Even such simple means yielded vast benefits. The 1979-1985 reduction in oil/GNP intensity corresponded by 1985 to annual savings equal to three times the 1986 U.S. imports from the Gulf. Just the 1973-1986 improvement in the efficiency of the U.S. car fleet, from 13.3 to 18.3 miles per gallon (mpg), provided in 1986 more than twice as much oil as the United States imported from the Gulf in that year, or as much oil as Alaska provided.[15] As will be seen, the additional potential for future vehicular efficiency improvements similarly dominates future oil savings–indeed, dominates all oil options on both the supply and the demand side.

In terms of market share, efficiency has quietly swept the field. During 1979-1986, the United States got:

- Fifteen times as much new energy from savings as from all net increases in supply from nuclear and fossil fuels
- Seven times as much new energy from savings as from all net increases in domestic supply combined[16]
- More than four times as much new energy from savings as from the increased gross output of coal and of nuclear steam[17]
- More new net supply from renewable than from nonrenewable sources

Specifically, the Energy Information Administration's *Annual Energy Review 1986* showed, from 1973[18] and 1979[19] through 1986, the absolute amounts (in q, or quadrillion Btu, per year) and percentage shares of increased total effective supply (see Table 7. 1). ("Effective supply" includes both new energy production and improved energy productivity–wringing more economic activity out of energy already being used.) The percentages of the total increase in effective supply are shown in two ways: including in that total (INCL) and excluding from that total (EXCL) the changes in output of domestic oil, gas, and natural gas liquids. The following table excludes renewable sources, such as wood, not shown in EIA's summary statistics; these sources' contributions will be partly accounted for later.

These data show, for example, that of the actual net expansions in effective primary energy supply (counting the decrease in fossil-hydrocarbon output), savings accounted for 92 percent of the total since 1973

TABLE 7.1

Effective Energy Supply Gain, 1973-1986, Excluding Renewable Sources

	1973-1986		1979-1986	
	q/y	INCL/EXCL[a](%)	q/y	INCL/EXCL[a](%)
Savings[20]	26.21	92.1/74.3	18.78	92.8/81.3
Coal[21]	5.52	19.4/15.6	2.87	14.2/12.4
Nuclear[22]	3.56	12.5/10.1	1.45	7.2/6.3
All other EIA Supply[23]	-6.84	-24.0/na	-2.85	- 14.1 /na
Total[24]	28.45	100.0/100.0	20.25	100.0/100.0

[a]Including and excluding oil/gas/NGLs.

Source: Energy Information Administration, *Monthly Energy Review*, September 1987.

and for 93 percent since 1979. (Komanoff's analysis, with which we concur, indicates a slight *acceleration* of savings during 1984-1986–contrary to the conventional wisdom that energy savings have recently slowed if not halted.) Expansions of nuclear power and coal combined accounted for only the remaining 32 percent and 21 percent of the total during the same periods.[24] As fractions of *gross* supply expansion, ignoring the declining oil and gas output, the coal-plus-nuclear fractions were smaller–26 percent since 1973 and 19 percent since 1979–while savings accounted for 74 percent and 81 percent of the respective total increases in effective supply.

An even more realistic assessment of absolute and relative contributions can be obtained by disaggregating "All other EIA supply" into fossil hydrocarbons, hydroelectricity,[25] and geothermal heat, and by adding very conservative estimates of output from some of the other renewable sources that are omitted from EIA's summary statistics[26] (see Table 7.2).

Thus the much-touted claim that nuclear power, for example, has been the key to displacing oil is clearly exaggerated. Since 1973, savings have outpaced nuclear expansion by sevenfold; since 1979, by nearly thirteenfold. Even the expansion in coal plus nuclear power combined was responsible for only 25 percent since 1973, and for only 18 percent since 1979, of the total gross expansion of U.S. energy supply. Komanoff noted that, during the two-year period 1985-1986, there was a further decrease in the coal-plus-nuclear share, to a mere seventh of the energy savings.[30] (In terms of opportunity, cost, indeed, coal and nuclear investments, far from contributing to oil displacement, have undoubtedly *retarded* it, as will be noted below.)

It might be objected that comparisons between savings and net increases in supply are between a large number and a very small one, since decreases in oil and gas output have been of the same order of

TABLE 7.2

Effective Energy Supply Gain, 1973-1986, Including Some Renewable Sources

	1973-1986		1979-1986	
	q/y	INCL/EXCL[a](%)	q/y	INCL/EXCL[a](%)
Savings	25.13	85.5/68.8	18.39	87.9/76.6
Coal	5.52	18.8/15.1	2.87	13.7/12.0
Nuclear	3.56	12.1/9,7	1.45	6.9/6.0
Oil/gas/NGL	-7.16	-24.4/NA	-3.07	-14.7/NA
HydroelectriCity[27]	0.75	2.5/2.0	0.34	16./1.46
Geothermal	0.18	0.6/0.5	0.16	0.7/0.6
Wood and wood wastes[28]	1.125	3.8/3.1	0.62	3.0/2.6
Other renewables[29]	0.28	1.0/0.8	0.18	0.9/0.7
Total	29.38	100.0/100.0	20.93	100.0/100.0

[a] Including and excluding oil/gas/NGLs.

Source: Energy Information Administration, *Monthly Energy Review*, September 1987.

magnitude as increases in conventional supply. But no such objection applies if the efficiency bonanza is expressed in *absolute* terms. The data in Table 7.2 show that the "efficiency industry" built during the fourteen year period 1973-1986 is now producing each year about two-fifths more primary energy than the century-old U.S. oil industry is extracting.[31]

Moreover, the efficiency industry has expanding reserves, output rising by several percent per year, and falling real costs, while the domestic oil industry has shrinking reserves, dwindling output, and rising real costs. Which industry merits, and is receiving, the marginal dollar of investment–the one scraping ever nearer the bottom of the old-province barrel, or the one just starting to tap a newly discovered and nondepletable barrel? In which industry can an investor make more profit, at less risk, over a longer period? That is the challenge, and the business opportunity, for the oil industry.

These data also show that since 1973, the United States has gained 3.5 times as much new energy from savings, or 3.8 times as much from savings and renewables combined, as it has lost from the decline in fossil hydrocarbon output. That is, the new "oilfields" being discovered in U.S. buildings, factories, and vehicles have been coming onstream several times as fast as the aging oilfields were petering out. In 1986, therefore, the energy already being saved each year (25.1 q/y), compared with 1973 levels of energy productivity, was equivalent to:

- 6.4 Alaskan North Slopes (each of 3.95 q/y) or
- 12.8 times U.S. imports from the Gulf (1.93 q/y) or

- 2.2 times total U.S. net imports of crude oil and refined products (11.5 q/y)

Even the inevitable minor corrections for behavioral and compositional changes, to isolate the effects of purely technical gains in energy productivity, can hardly change the conclusion: Energy efficiency represents an extraordinary and largely unrecognized bonanza. Because of it, the share of U.S. oil consumed that was imported (net) fell from 46.5 percent in 1977 to 27.3 percent in 1985; the absolute amount of imported oil fell by half. Since stock changes were immaterial, this means that oil *was being saved faster than more oil was being needed.*

So What Happened in 1986?

Both of the periods just analyzed, 1973-1986 and 1979-1986, reflect increased domestic energy efficiency elicited by price shocks. To understand whether the great savings achieved in those periods can be expected to continue–whether, for example, it is safe to extrapolate from the abrupt (if minor) reversal of aggregate national oil saving in 1986–we should examine more closely the behavior of U.S. oil productivity gains over time.[32] Accepting for heuristic value the extremely aggregated measure of gross national product, with all its well-known faults, we see that those gains are conveniently represented by the annual percentage decrease, compared with the previous year, in the ratio of total petroleum consumption to real GNP[33] (see Figure 7.1). Real oil prices are summarized by one surrogate–leaded regular gasoline–because cars represent the largest single use of oil. Figure 7A reveals a striking correlation between price movements and oil-productivity movements. Of course, the detailed causality is vastly more complex than consumers' merely watching price movements, but even this simple correlation appears to have some explanatory and even predictive value.

Figure 7.1 shows how energy users' and suppliers' responses at first stuttered in the mid-1970s. Falling real prices after the initial 1973-1974 shock, and confusion about how best to respond to that unique transformation of global energy markets, led to incoherent responses. Regardless of what policymakers said or did, however, increased energy efficiency gradually emerged as a major force in the marketplace. Further stimulated by the second price shock in 1979-1980, national oil productivity gains accelerated steadily during 1978-1981, reaching an impressive pinnacle with the 8.4 percent/y gain in 1981. This sustained success contributed significantly to softer prices. The gradually decreasing annual falls in real oil prices during 1982-1985 were correlated with a gradual decrease in the rate of oil savings–but the 1982-1985 average

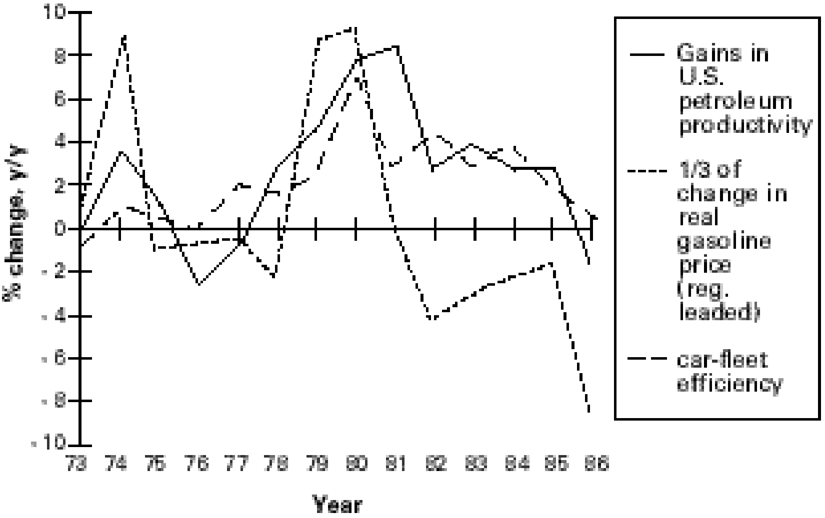

FIGURE 7.1 Gains in U.S. petroleum productivity and change in real gasoline price. Source: Adapted from data in Energy Information Administration, Monthly Energy Review, September 1987.

savings rate was still an important 3.2 percent/y. Only in the single year 1986, with prices crashing to below their real 1973 levels, did the nation slip from this plateau of steady progress into the first actual decrease in oil productivity (by 1.5 percent) since 1977.

A closer look at what drives improving oil productivity reveals that 1986 combined many extraordinary and uncharacteristic events. Figure 7.2 shows a generally strong correlation between movements in oil savings and in the average efficiency of the passenger-car fleet. Overlain on this variable, however, with about half its weighting, is the far more volatile productivity of oil in industry. The extreme volatility of this factor is due in substantial part to short-term fuel switching impelled by the changing marginal cost relationship between residual oil and natural gas. In 1986, the average untaxed end-user price of residual oil fell to a phenomenal 34¢ a gallon–27 percent below its real 1978 level (the earliest comparable data available). Not surprisingly, while 1986 real industrial output rose by 1.1 percent, industrial gas use fell by 5.5 percent and oil use spurted ahead by 3.0 percent, yielding a (3.0 - 1.1) = 1.9 percent loss in industrial oil productivity. Bargain-hunting utility fuel buyers likewise bought 36 percent more heavy oil in 1986 than in 1985, reversing a decade-long pattern that had seen a steady 73 percent decrease in utility oil burning during 1978-1985.

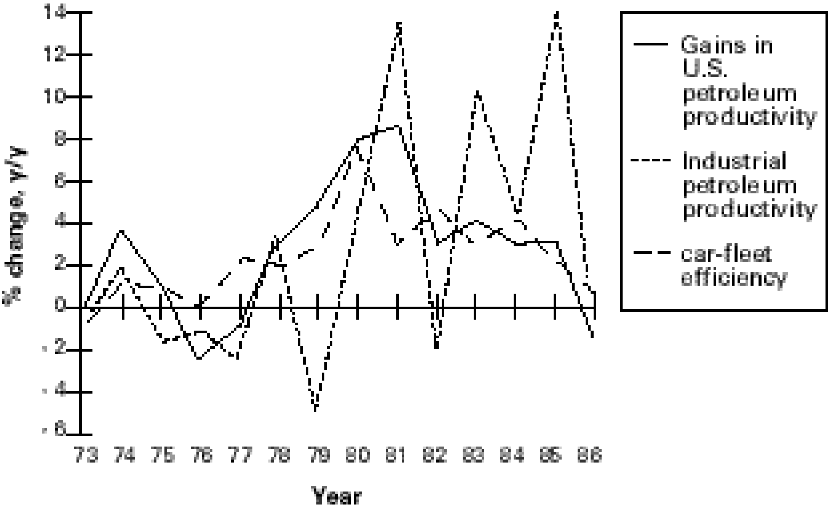

FIGURE 7.2 Gains in U.S. petroleum productivity and industrial petroleum productivity. Source: Adapted from data in Energy Information Administration, Monthly Energy Review, September 1987.

At the same time that industrial and utility oil productivity was thus falling, the Reagan administration stalled the previously steady improvement of the 18.2-mpg car fleet, on which virtually *any* new car was an improvement: Average new 1986 domestic cars had an mpg rating of 26.9 mpg, imports 30.9 mpg, and their mix 28.1 mpg, nearly 10 mpg above the whole-fleet average. The stall's proximate cause was a rollback of 1986-1988 new car standards: an action apparently meant as a mere favor to General Motors (GM) and Ford, but with serious results for the nation.

The rollbacks arose because Ford and General Motors have failed[34] ever since model year 1983 to meet Congress's 1975 sales-average efficiency standards, which Chrysler has met every year. Ford's and GM's model-year 1984 (cars released in fall 1983) noncompliance incurred no penalty because they used a 1979 amendment to "carry forward" offsetting credits for earlier "overcompliance." When their continued model-year 1985 noncompliance was then penalized, the Reagan administration, by regulatory decision out of public view, obligingly rolled back the model-year 1986-1988 standards to levels they could beat, so they could retroactively offset the uncollected penalties with new credits. (This still was not enough to bail out GM, so a retroactive rollback of the model-year 1985 standard is now also being considered.) This rollback:

- Cost the Treasury more than $1 billion (a direct gift from taxpayers to GM and Ford shareholders)[35]
- Told both firms they could defy Congress with impunity
- Penalized Chrysler for obeying the law
- Most importantly, signaled Ford and GM to intensify their ferocious marketing of less efficient (but more profitable) models

The resulting sales crusade of Ford and GM did much to cut the 1985-1986 gain in U.S. whole-car-fleet efficiency to a ten-year low of 0.12 mpg– 89 percent below the 1979-1985 (post-CAFE–U.S. car fleet efficiency standards) average–while similar light-truck rollbacks cut the new truck efficiency gain by 67 percent. This stall in previously steady progress directly accounted for an increase in crude oil imports of ~295,300 B/D–equivalent to a doubling of 1985 imports from the Gulf.[36]

Simultaneously with this blunder, threats of terrorism in Europe and a 1985-1986 drop of ~27 percent in real gasoline prices contributed to 0.7 percent heavier summer driving in 1986–barely noticeable, but the highest level since 1978. Together with a 2.7 percent one-year increase in car registrations (probably spurred by the automakers' aggressive rebates), half again as high as normal, the net result was a 3 percent increase in 1986 sales of motor gasoline.

Are the circumstances that conspired to convert the unprecedented 1986 price collapse into a 1.2 percent decrease in national oil productivity a harbinger of an emerging supply/demand imbalance in the years ahead, as many industry observers insist? Based on the most recent two year record currently available, just the opposite seems likely. During 1985-1986,[37] many stripper wells were lost, the domestic output of oil and gas fell by 1.96 q/y, and total net oil imports rose by 164 q/y. Yet simultaneously, energy savings soared by 3.90 q/y, with 3.48 q/y of those savings being achieved directly in the use of oil and gas.[38] Thus Americans saved 78 percent more oil and gas in those two years than was lost in domestic output.[39]

The only reason net oil imports rose during 1984-1986 is that GNP grew by more (6.0 percent) than oil productivity improved (2.3 percent–a 3.5 percent gain in 1985 offset by a 1.2 percent loss in 1986), so oil consumption rose by 3.5 percent–essentially equal to the difference between these figures. But meanwhile, domestic crude output fell by 2.5 percent, increasing imports by nearly the sum of rising consumption plus falling output. This increase in imports was 2.58 q/y–only 8 percent of 1986 oil consumption, but a more dramatic-sounding 29 percent of 1985 imports.

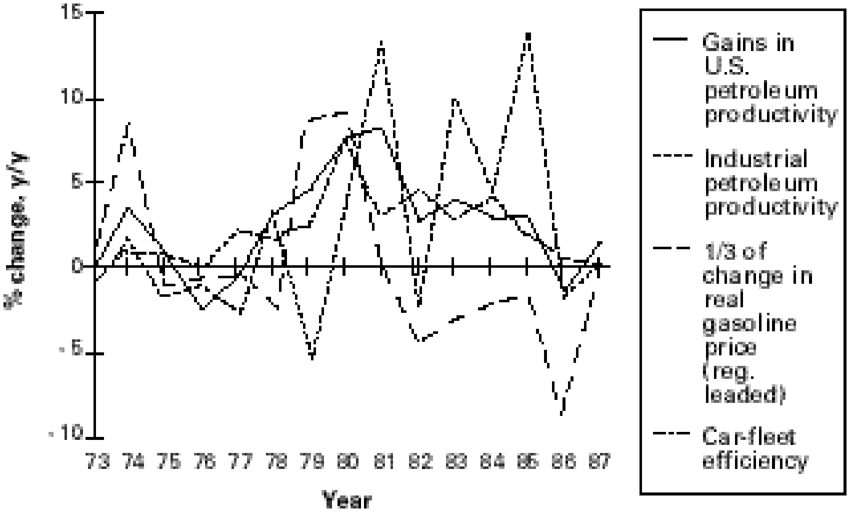

FIGURE 7.3 Gains in U.S. petroleum productivity, industrial petroleum productivity, and change in real gasoline price.
Source: Adapted from data in Energy Information Administration, Monthly Energy Review, September 1987.

It should be remembered, however, that during 1977-1985 the average rate of improvement in oil productivity was an impressive 5.0 percent per year. Nothing has fundamentally changed the causal relationships and processes underlying this trend. It therefore appears highly likely that 1986's *minus* 1.2 percent oil-productivity change was an artifact of a coincidence between a unique price movement (itself largely a consequence of past efficiency gains) and the administration's ill-advised effort to help GM and Ford escape the consequences of their persistent noncompliance with the 1975 CAFE standards. Though reliable statistics are not yet, at this writing, available for 1987, we venture to predict that as prices rise again, even if slowly, and even with relatively stable real prices at pre-1966 levels, oil productivity will again rise on much the lines shown for the past decade in Figure 7.1. Preliminary EIA data for 1987[40] (see Figure 7.3) seem consistent with this hypothesis: U.S. oil productivity rose more in 1987 than it fell in 1986.

It is hard to avoid the conclusion that even under the exceptional circumstances of 1986-1987, despite federal indifference or antagonism to efficiency, America's oil supply/demand balance has been getting better, not worse. It is gaining efficiency faster than it is losing field output: The country is seeing a *shift* of energy "source," not a loss of its ability to "produce"– as either barrels or negabarrels– enough effective supply to meet its needs. The fundamental causes of this are not immutable, but they *are* durable, as will be shown next.

During 1979-1986, real GNP grew at an average rate of 2.12 percent/y, while domestic oil output fell at an average rate of 0.03 percent/y. Together, these trends would require an increase of 2.14 percent/y in oil productivity to hold imports constant. Yet over the same period, the United States saved oil four-fifths faster than that (averaging 3.88 percent/y), significantly increasing its ability to live within its domestic oil budget. Moreover, this was achieved more in spite of than because of national policy: The period 1979-1986 was replete with federal neglect of efficiency ranging from benign to possibly malign, and with often misguided and counterproductive government messages that confused efficiency with curtailment, discomfort, and privation, The United States has never mounted a thoughtful, systematic policy commitment to an energy-efficient economy, As will be shown below, *much* better performance can be achieved with high confidence by simply making high oil productivity a policy goal and using proven methods–market, regulatory, or both–to apply what is now known.

Transportation: The Dominant Term

In 1985, a year representative of the mid-1980s, 65 percent of all oil consumed in the United States (roughly twice the Japanese and Western European share), or 19.56 q, was used for transportation. This transportation fuel use was equivalent to *thirty times* that year's imports from the Gulf (0.64 q), or 7.6 times the total net petroleum imports from all sources (2.57 q). An efficiency gain of 3.3 percent, therefore, would have eliminated 1985 oil imports from the Gulf. Only 4 percent of all U.S. transportation energy in 1984 was provided by forms other than oil. Of the oil thus used, approximately[41] 75.5 percent went to highway vehicles–47 percent of the total to cars and 14 percent to light trucks,[42] 14 percent to 40 million heavy trucks, 0.7 percent to 0.6 million buses, and a negligible amount to 5 million motorcycles and other small vehicles. Constituting the 24.5 percent of 1985 transportation oil used by nonhighway vehicles was an estimated 8 percent of the total for ships, 8 percent for commercial and private aircraft, 3 percent for trains,[43] 2 percent for pipelines,[44] and 3.5 percent for "other (including military)."[45]

It is interesting that the Department of Defense (DOD) in FY1986 consumed 83 percent as much oil as the total annual U.S. imports from the Gulf (averaged over 1984-1986)–mainly for the aircraft and ships on which theater operations in places like the Gulf are highly dependent, DOE stated that a major conventional conflict would increase DOD's oil use by two- or threefold. Thus a major conflict centered on the Gulf could plausibly *use* more oil than the United States gets from the Gulf.[46]

DOE reported[47] that total U.S. freight energy intensity would have declined by 13 percent during 1972-1986–slightly more than passenger energy intensity's 11 percent–if there had not been a shift toward the less fuel-efficient modes. (Passenger travel would have shown a 12 percent energy-intensity decline at the 1972 mode mix, but there was a shift from surface to less-efficient air travel.) It is interesting to note that, during 1972-1986, the economy became no more travel intensive: Passenger miles traveled by all modes per dollar of real GNP was constant, but the number of tons of freight shipped per dollar of GNP declined by an impressive 30 percent. Since the number of ton-*miles* per dollar of GNP fell by only 3 percent, one can infer that the average number of miles shipped per ton rose by some 27 percent, reflecting the rapid increase in air freight services and an increase in imports through coastal gateway cities requiring reshipment inland (imported tonnage grew by 100 million tons, while domestically generated tonnage fell by 176 million tons or 3.6 percent of the 1986 domestic total). Thus of the 8 percent reduction in freight energy consumption per dollar of GNP, five percentage points came from improved efficiency and three from structural change; the efficiency gain would have been twice as great had a shift to less-efficient modes not simultaneously occurred.

The U.S. transportation sector has so far achieved by far the smallest intensity reduction of any end-use sector: Its share of U.S. oil rose from 51 percent in 1973 to 65 percent in 1985 as other sectors saved or substituted more. Yet transportation has far from the smallest savings *potential. For* illustration, a marginal improvement of 1 mpg in the productivity of a single average U.S. light vehicle translates into a gasoline saving of about 0.8 barrel per year. With 136 million passenger cars and light trucks registered in 1986, and conservatively assuming the product slate is all gasoline, that 1-mpg fleet gain corresponds to ~0.30 MMB/D–essentially equal to total 1985 imports from the Gulf (0.31 MMB/D), or to a third of the unusually high 1986 Gulf imports (0.91 MMB/D).

It is therefore especially bewildering that the Reagan administration places such emphasis on using oil more quickly and saving it more slowly. Just the above-mentioned rollback of 1986, 1987, and 1988 new car efficiency standards from 27.5 to 26 mpg,[48] carried through the next replacement car fleet, will waste more oil[49] than currently forbidden lease areas in the Arctic National Wildlife Refuge (ANWR) or offshore California might yield, if they turned out to contain any oil, during the same period.[50] Indeed, the 1986 light-vehicle-standards rollbacks may

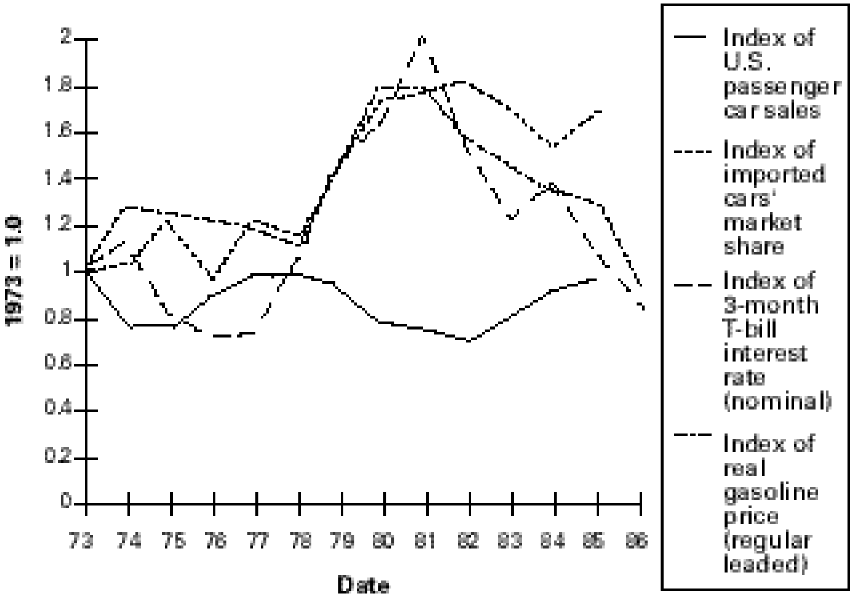

FIGURE 7.4 U.S. passenger car purchasing behavior and interest rates.
Source: Adapted from data in Energy Information Administration, Monthly Energy Review, September 1987.

be said to have *un*discovered the equivalent of the hoped for mean ANWR reserve: the resulting ~295,300 B/D increase in crude oil imports (counting the 1.88:1 crude:gasoline ratio) happens to equal the average output of a 3.23 billion-bbl reserve extracted over thirty years.

The historic behavior of U.S. car buyers, while complex in detail, is surprisingly simple in broad outline. Figure 7.4 shows the correlations between real gasoline price and imported cars' market share; the inverse correlation between the rate of car purchases and nominal interest rates; and a suggestive correlation between those interest rates and the real price of gasoline. The relationship between the speed of additions to the car fleet and the improvement in fleet-average efficiency (Figure 7.2) is weak; the efficiency of the new cars, and the rate of scrapping the worst old ones, is more important than the turnover rate. This is not surprising, since fleet-average *efficiency* is a geometric, not an arithmetic average: The worst cars drag down the fleet average disproportionately.[51] Moreover, there is a strong correlation between car efficiency and household income: Gas-guzzlers have trickled down to the poorest people, who can afford neither to run nor to replace them.

Potential Light-Vehicle Efficiency Gains

Car-fleet efficiency is widely recognized as the most important single variable in U.S. oil prospects. For example, the Department of Energy assumes a "market" scenario in which, with no policy intervention,[52] new cars and light trucks will average 30 and 25 mpg respectively by 1990 (the level currently planned by only one of the three major U.S. carmakers), with no improvement thereafter. Compared with constant new vehicle performance through 2020 averaging 27 mpg for cars (close to Congress's prerollback 1975 standards of 27.5 mpg for 1986-1988 cars) and in the low 20s for light trucks, the cumulative saving would be 1.3 billion barrels by 2000 and *6.0 billion barrels* by 2020.[53] The former figure is about twice, and the latter about ten times, the risked mean oil reserves, undiscovered and economically recoverable at implausibly high prices under favorable (pre-1986) tax law, beneath the Arctic National Wildlife Refuge.[54] The 2020 figure is also equivalent to about two-thirds of a Prudhoe Bay supergiant field of 9.4 billion bbl.

How much more could be done with straightforward extension of the CAFE standards? If new cars and light trucks achieved respectively 45 and 30 mpg in 1998, rising to 60 and 45 mpg in 2008, then the fleet would save 2.9 billion bbl by 2000 and a staggering 22.8 billion bbl by 2020 (both compared with the 27- and 19.5-mpg base case). Even if the DOE "market" assumption of 30/25 mpg by 1990 were subtracted, the standards' cumulative *net* savings by 2000 (2020) would still total 1.6 (16.8) billion bbl, This 2020 net saving is three times the mean risk undiscovered oil officially estimated to be economically recoverable at very high prices (if present) offshore Alaska plus California. That 16.8 billion barrels is also 27 times the risked, or 5.2 times the unrisked, mean reserve hoped for in ANWR.[55] It would be like discovering a whole new ANWR every thirteen months. Yet the rhetoric about how crucial ANWR oil (if it exists) would be to national security seems not to carry over to the 27-fold larger (when also risked) oil resource sitting untapped in the inefficient U.S. light-vehicle fleet– or 51-fold larger if adjusted to reflect the 1.88:1 ratio of crude oil input to gasoline output.

Nor would 60/45 mpg standards push existing technology in the least.[56] A glance at the annual *Gas Mileage Guide* reveals that the 40- to 55-mpg efficiency range, often achieved with the help of smart-chip-controlled fuel computers, is now commonplace from a variety of U.S. and foreign vendors. Aerodynamics, tires, suspensions, lighter weight materials, engine designs, finishes, clutches, transmissions, bearings, lubricants–all are continuing steady incremental improvements. Such once implausible technologies as continuously variable transmissions, "idle-off " engines (which turn off when idling and instantly restart when needed), ultralean-burn engines, variable-displacement engines (which deactivate some cylinders at low loads), variable valves, composite leaf springs and wheels, plastic body panels, composite and light-alloy drive shafts, and liquid-injection-molded tires–all are already on the market.[57]

DOE's July 1985 conservation plan projects a 28-mpg car fleet–0.5 mpg worse than the average 1988 car being sold that year, and exactly half as efficient as the most efficient U.S.-made 1988 car–*in 2010*, two fleet-turnover intervals from 1988. DOE further asserts an estimated "potential" to achieve a 39-mpg fleet in 2010 "with successful R & D effort." Yet acting out early-1980s projections that existing technologies could achieve 70-80 mpg,[58] most leading carmakers; *have already tested* four- or five-passenger prototypes, similar in size and performance to many ordinary cars now on the road, but getting ~70-100+ *composite mpg*.

Bleviss[59] cited seven manufacturers whose prototypes have on-road composite ratings >67 mpg. Volvo, for example, has a 71-composite mpg LCP-2000 ready for production. It accelerates 0 to 60 mph in 11 seconds–2.1 seconds faster than the average new U.S. car (rated at only 28 mpg) could do in 1986. It would be one of the most crashworthy cars on the road and would meet all U.S. emissions standards. Volvo expects that at break-even production of only 20,000 units a year, the LCP-2000 would cost *about the same* as an average subcompact today. This illustrates a surprising but apparently general finding: In many lightweight car designs, the saving on the amount of materials, number of parts, and fabrication labor (since large, previously complex parts can be molded in one unit) can make up for the higher cost of the lighter and stronger materials.

Furthermore, Renault, Peugeot, Ford, and Toyota (with a 56-hp, 98 mpg prototype compact) all have >71-mpg prototypes. Their experience confirms that such efficiency can come with comfort, performance, safety, and environmental standards at least equal to those of the inefficient cars of 1988. One of the most impressive new prototypes, a Renault Vesta 2 four-passenger prototype outwardly akin to the standard R5 model, did 146 mpg highway at 62 average mph in recent 311-mile road tests.[60] Its U. S. on-road city rating (as computed from European-standard city tests) is 101 mpg, for an on-road composite rating of 121 mpg. It has a top speed of 87 mph, a 27-hp/4250-rpm three-cylinder fourstroke engine displacing 716 cc, and a curb weight, by various accounts, of a mere 1043-1146 pounds. Its drag coefficient is only 0.19, compared with 0.48 for the average U.S.-made car in 1979 and with -0.3 for "slippery" production cars today. (Ford, however, measured a draft coefficient of only 0.137 in its Probe V prototype–lower than for an F-15 jet.[61]) One could do even better than the Vesta 2 with a continuously variable transmission instead of the manual 5-speed, more exotic materials such as lightweight but very crashworthy metal foams (the current model uses an all-steel frame and hood with composite roof and floor), or other developmental technologies such as ceramic engines (announced by Isuzu for 1990 models) or oxygen-enriching membranes on intake air.

Still further savings could be had by introducing small commuter vehicles, perhaps more advanced than the two million-odd “minicars” (no more than 4.5 x 10.5 feet and 550 cc) that hold a fifth of the Japanese domestic market. General Motors, for example, has invested more than $50 million in developing a one- or two-passenger, ~3/4 liter “Lean Machine,” which typically gets 150-~200 mpg, is said to be safer than a normal car because it is highly maneuverable, has an extraordinarily small turning radius, and occupies in driving or parking less than half the width of a normal car. Although its manufacture and marketing have been licensed to Opel (Europe) and Suzuki (United States), its release is held up by regulatory uncertainties. (Is it a car, a motorcycle, or what? What sort of license, registration, and insurance does it need? Is it legal to drive it two abreast? And so on.) Any state could probably choose to remove these barriers.

Though variously derided and neglected, mass transit, too, shows impressive progress in certain sectors. U.S. buses, perhaps because so many are operated by the public sector, were no more energy efficient in 1984 than in 1974:[62] Their average 5.90 mpg was 1.3 percent worse than in 1976-1977. (This often reflects poor operation and maintenance practices.) Yet striking advances have been made elsewhere in the technical efficiency of buses and, notably in Brazil, in managerial innovations that greatly reduce the costs, delays, and hassle of commuter bus service[63] so as to increase ridership. Both U.S. and European progress with trolleys, minivans, and subways is also encouraging. Even with standard (and usually overengineered) U.S. techniques, Robert Watson has calculated that fuller practical use of mass transit could add an extra 2.0 billion barrels by 2020 (3.2 risked mean ANWRs) to the mpg-standards net savings of 16.8 bbl described above.[64]

Other Transportation Efficiency Options

Surprising technical innovations are rapidly becoming available for noncar road vehicles too. The average U.S. heavy truck improved from 8.4 to 10.3 mpg during 1974-1984, largely through aerodynamic cowlings, slightly better engines, and fuller use of radial tires, whose share among heavy-heavy trucks increased from 22 to 44 percent during 1977-1982.[65] Unit trucks during 1974-1984 reduced their energy use per vehicle-mile by 22 percent while combination trucks increased it by 6 percent. Far greater heavy-truck energy savings– upward of 40 percent– are now available from turbocharged and adiabatic (uncooled) low-friction engines, improved controls and transmissions, better tires and aerodynamics, exhaust heat recovery, regenerative braking, and, the like. Improved payloads and reduced empty back hauls (return trips) through better shipping management can also make important contributions. Together, these approaches can save about 60 percent of heavy-truck energy.[66] Furthermore, for regular shipments between defined areas such as particular factory clusters, GM's commercially available "Roadrailer," convertible in seconds from a heavy truck trailer to a railcar or vice versa, saves about 75 percent of 18-wheelers'energy, and more than pays for itself just by faster (100+ mph) and surer delivery of undamaged contents.

What of nonroad vehicles? Domestic waterborne commerce has already reduced its energy intensity per ton-mile by nearly half during 1973-1983. In marine transport, improved propellers, engines, hull defouling, and other innovations are saving ~25 percent, and high-tech sails and heat recovery have raised the saving to 50+ percent in some tests. Train efficiencies can be substantially boosted too, to say nothing of fuel substitution–electricity for dense corridors, fluidized-bed coal or alternative liquid fuels for low-density ones.

The 757/767/DC9-80 generation of commercial airliners is twice as efficient as the fleet it replaces, getting 45 passenger-miles per gallon, compared with 17.5 for the 1973 fleet, and–due to operational as well as technical improvements– ~33 for the 1988 fleet. Still newer aircraft now in flight testing, some using modern airscrews attached to turbofans, will save another ~40 percent. More experimentally, maneuverable lighter-than-air craft continue to show promise for door-to-door containerized freight delivery.

In sum, one could do even better with today's transportation technologies than the Solar Energy Research Institute's (SERI's) remarkable team effort concluded in 1981.[67] SERI assumed a U.S. transportation system that in the year 2000 (compared with 1977) moves 17 percent more Americans, increases per capita personal travel by 30-70 percent in cars and 60-90 percent in planes, and raises freight ton-miles by 80 percent in trucks and 300 percent in planes. Nonetheless, transportation energy would fall from 19.5 q in 1977 to 12.6-16.5 q in 2000 (or to as little as 11.8-16.0 q of fuel with aggressive electrification, using an additional 0.75-1.15 primary q of electricity). Of this fuel requirement, the team estimated that as much as 5.5 q could be cost-effectively supplied by renewables (chiefly biomass methanol) in 2000, leaving as little as 6.3 q of transportation oil demand. And that calculation was based on projected technological improvements– to 60 mpg for cars, by 30 percent for planes, and so on– which have *already* been far surpassed. One begins to see, in light of this finding, how Royal Dutch/Shell planners can reportedly regard as plausible an unpublished recent scenario in which the United States, in the year 2000, has reduced its oil imports to zero.

Light-Vehicle Efficiency: Economics and Policy

As of 1984, only about a fifth of the total cost of owning and operating a car (~19-22 percent, depending on size) was its gasoline cost, when that averaged $1.20 a gallon (1984 $). Any factor cost whose fraction of total cost is so small clearly provides a weak price signal for buying an efficient car. Indeed, many analysts have remarked that over a range of perhaps about 20 to 50 or 60 mpg, the total cost of owning and operating an otherwise unchanged car is essentially flat: The more efficient car costs about as much more to buy as it costs less to run. Though such early-1980s projections badly need to be updated– both fuel and efficiency now look cheaper than was commonly assumed a few years ago– there is still certainly some range over which the conclusion holds. Within that range, normal price signals provide virtually no incentive for purchasing a more efficient car. This was empirically demonstrated in the early 1980s, when gasoline prices went to $1.35 a gallon, yet it is very doubtful that domestic carmakers would have offered far more efficient cars were they not forced to do so by law.[68]

Worse, at efficiencies above ~30-40 mpg (250-333 gal/y @ 10,000 mi/y), extremely large increases in fuel prices would be needed to provide a significant signal because so little fuel would be burned; yet there would still be room for a further approximately two-to-three-times efficiency gain with major benefits to the nation. This suggests that perhaps in the short run, and certainly in the long run, policy instruments should emphasize influencing the car-buying decision *directly* rather than via fuel prices. This is true regardless of whether one considers the inability of low-income people to afford any replacements for the inefficient cars that they tend to own (if they own any).

It is therefore worth comparing the cost of signals that *would* provide a direct incentive for car efficiency with the cost of competing supply-side investments. Although such an analysis is beyond the scope of this chapter, we did point out in the late 1970s that rather than building synfuel plants, the United States would save more oil, faster and cheaper,[69] by:

- Giving away a free 40+-mpg car in return for scrapping an old Brontomobile or

- Paying a $300+ cash bonus for each mpg[70] by which a new car improves on an old Petropig which is scrapped– or a corresponding bounty for scrapping an inefficient car that *is not* replaced

Unfortunately, despite a decade's sporadic effort, we have been unable to get anyone, including DOE and the carmakers,[71] to do a *serious* analysis of accelerated scrappage of gas-guzzlers as a cheap source of oil, (DOE did sponsor one analysis of scrappage, but under such artificially restrictive assumptions that virtually no benefit could result.[72]) None of DOE's voluminous analyses of oil-saving policy options mentions it. In fact, when we injected these two comparisons into a discussion at the 1986 meeting of the International Association of Energy Economists, many economists in the audience asked the previous speakers (who had called for massive synfuel investments) whether there was something wrong with our numbers. No, they agreed; the back-of-the-envelope arithmetic was impeccable.[73] So why, the audience persisted, were the speakers pushing synfuels? Because, they replied, it is inconceivable that Congress would do anything that is economically rational, so one must *start* with the second- or nth-best solution. This flippant reply reflects a real problem: a national preoccupation with "moon-shot"- or Manhattan-project-style big "solutions" such as the synfuels program and a corresponding mistrust of bottom-up, market-driven solutions.

The cynical economists might also have recalled that the Carter administration proposed rebating gas-guzzler taxes to buyers of efficient cars but dropped that interesting idea because at that time the only efficient models available were Japanese. Today, however, with efficient U.S.-made cars available and with empirical proof (provided by the manufacturers themselves) that car buyers respond substantially to rebates, what Bleviss called the "'gas-sipper' rebate" is ripe for revisiting. Without federal action and hence preemption, as she pointed out, states could also set their own efficiency standards (as California did with appliances, ultimately taking the country with it), or could make their annual car-ownership taxes large and progressive. For example, Sweden, which has only the population of Los Angeles County, has a progressive weight-based car excise tax that strongly influences the fleet's weight distribution[74] (weight is the single most important determinant of car efficiency). Several state governments in the Northeast, plus California, have expressed interest in state or regional standard tax rebate packages to fill the expanding federal regulatory void and try to correct market failures in car purchases.

We also noted in 1981 that if the U.S. auto industry, which planned to spend $100 billion on retooling during 1985-1995, spent twice that much (probably at least five times more than it would actually cost) on marginal retooling to convert production directly to a 60-mpg average, and then spread that probably overstated cost over the next new fleet of cars and light trucks, the average cost per vehicle would rise by less than $800, and at the 1981 gasoline price, buyers would receive a fourteen-*month* payback.

In view of this potentially large return to consumers and society, it is long past time for entrepreneurs– especially those in the oil industry now drilling against ever greater odds– to give careful thought to how they can capture the rent from car efficiency. For example, might wildcatters and oil majors (antitrust questions aside) invest in the carmakers' efficiency retooling, or in purchasers' marginal investments? Can one imagine an oil company-sponsored car credit company that invests in costlier but more efficient cars on a shared-savings basis?[75] Once oil companies find that it is cheaper to buy each other (hence reserves in the ground) than to drill, is it such a large step to start buying the even cheaper negabarrels in not-yet-purchased automobile gas tanks?

On early-1980s data, it could be said that in the lower-48 states are two supergiant oilfields, each bigger than the Ghawar field, the largest in Saudi Arabia; each able to product sustainably (not just to extract once) over 5 million barrels per day for less than $7 a barrel; each largely untapped; and each capable of *eliminating* the level of U.S. oil imports then prevailing (5.4 MMB/D), before a synfuel plant or power plant or frontier oilfield ordered at once could produce any energy whatever, and at about a tenth of its cost. These two oilfields were, of course, the "accelerated-scrappage-of-gas-guzzlers oilfield" under Detroit[76] and the "weatherization oilfield" (including saved gas fungible for oil) in the nation's attics. Today, both those oilfields are still there, roughly 80 percent untapped; indeed, improved technology has expanded their reserves and reduced their finding and lifting costs. If you went to the ends of the earth to drill for very expensive oil, which might not even be there, while someone else found all that cheap oil under Detroit, would you not feel a twinge of embarrassment? By investing in frontier drilling instead of modernizing the U.S. car industry, do U.S. decision makers not simultaneously make boomtowns in the Arctic and ghost towns in the industrial heartland?

Of course it is true, as a managing director of Royal Dutch/Shell once remarked, that once you sell a man a "negabarrel," he has it, and you can't sell it to him again. But it is equally true, as we replied, that once you sell him a barrel of oil, you don't have *it* any more, so you can't sell it to him again either. The issue should be, which kind of investment and sale will lead to the maximization of profit and the minimization of regret? Light vehicles are certainly the most promising new oil province to start exploring.

Saving Oil in Buildings

Oil burning in U.S. buildings fell by 41 percent during 1973-1986, leaving only 2.57 q/y of residual consumption. Nearly all of that is for space heating, two-thirds of it in the Northeast. Although relatively small– only 8 percent of U.S. oil use in 1986– oil use in buildings cannot be considered in isolation from the far larger use of natural gas in buildings for similar purposes (6.97 q in 1986, or *42 percent* of that year's total gas use).[77] These two fuels are interchangeable in a wide variety of uses, particularly in industry. They can be significantly substituted even in transportation.[78] Options for saving them in the buildings sector therefore are worth considering together, so as to expand options for substitution in both transport and industry. Furthermore, gas can be widely substituted for oil *within* buildings (especially with the help of cheap new distribution-pipe and -installation technologies). Whether saved through efficiency or substitution, the 2.57 q of oil burned in U.S. buildings in 1986 is equivalent to one and a third times the nation's 1986 imports from the Gulf.[79] Over a decade, it is also equivalent to some 4.4 billion barrels of crude oil, or 1.33 times the risked mean reserve that might exist under unexplored parts of onshore Alaska, or nearly seven times the risked mean reserve claimed for ANWR.,

The Department of Energy has developed a "market" scenario for weatherization in households, which account for about 82 percent of all the oil used in buildings. This scenario assumes, somewhat optimistically in view of recent budget cuts, that 20 million homes will be retrofitted by 1998 so as to save ~32 percent of their current oil use. Robert Watson calculated that a more widespread program, using better technologies more fully to save ~55 percent in 53.5 million single-family homes over the same period, would yield incremental savings of ~1.7 billion barrels of oil, or ~7.6 billion barrels of oil, gas, and LPG, by 2020. (Utilities and public agencies have cost-effectively demonstrated such savings in many parts of the United States.) The lower figure is about 2.4 times the risked mean oil reserve for which Secretary of the Interior Donald Hodel wanted more drilling off the Atlantic Coast.

That potential saving, however, arises only from reducing heat flow through the buildings' shells. Additional, and synergistic, savings are available from improved space- and water-heating appliances. Watson's retrofit case modestly assumes converting furnaces from an average Annual Fuel Utilization Efficiency (AFUE) of 0.68 to 0.90, converting water heaters from a recovery efficiency of 0.75 to 0.90 and a standby loss of 4.9 percent/h to 2.0 percent/h, and changing showerheads from 5.0 to 2.5 gallons per minute (gpm). All these assumptions fall well short of economically attractive options now on the market, including furnaces up to AFUE-0.97 and high-performance showerheads down to 1.2-1.5 gpm. Nonetheless, the cumulative saving by 2020 from using these modestly efficient appliances in all existing oil- and gas-burning homes would be 4.5 billion barrels-equivalent–about two-fifths more than the risked mean reserves hoped for under onshore Alaska. Similar improvements in the new homes built over the next few decades would add another 0.8 billion barrels'savings, and those new homes' shell improvements, another 1.0 billion barrels' worth of space-heating.[80] Counting multifamily dwellings would further increase these savings.

The SERI analysis cited earlier found, by empirically based supply-curve analyses done in previously unprecedented detail, a practical potential to save during 1977-2000 some 7.7 q/y of fuel (essentially all oil and gas) in buildings still standing by 2000. (Achieving that saving linearly would imply an average saving of 2.68 q/y; the actual saving during 1977-1985 was 2.04 q/y, somewhat behind schedule, but was achieved by generally less thorough retrofits than the SERI/LBL [Lawrence Berkeley Laboratories] group assumed.) The team assumed increases during 1977-2000 of 17 percent in population, 10 percent in the average floor space of new homes, 59 percent in commercial floor space, and 33 percent, 56 percent, 39 percent, and 59 percent in the saturation of central air conditioners, dishwashers, freezers, and swimming pools respectively. Yet they found a cost-effective potential to save by 2000 some 58 percent of fuel, and 33 percent of total energy, used annually in U.S. buildings.

Just standard weatherization techniques– insulation, weatherstripping, caulking, furnace tuneups, better showerheads, and the like– can save oil and fungible gas equivalent to upward of half of the 5.0 million bbl-equivalents-per-day (9.54 q/y) used in U.S. buildings in 1986. The SERI/ LBL analysts found, for example, a practical potential to save in existing homes (using circa 1979 technologies and a 3 percent/y real discount rate) half of all space-heating fuel at 1986-$ costs of $17/bbl marginal or $10/bbl average. A 75 percent saving, they found, would cost about $66/bbl marginal but only $20/bbl average, with the average cost of the incremental savings from 50 to 75 percent being about $28.6/bbl. (Many empirical program costs have since proved to be substantially lower than these.) In contrast, in 1985 and 1986 respectively, the average retail barrel of #2 heating oil was priced at $45.00 and $35.00; the average barrel-equivalent of residential natural gas, at $34.50 and $33.00. Thus the average cost of the 50 percent to 75 percent space-heating fuel savings would be about two to three times less than 1986 average retail fuel costs, let alone the far higher marginal costs of frontier hydrocarbons or synfuels.

A 50 percent saving in 1986 residential oil and gas use would be equivalent to two-and-a-half times the 1986 U.S. imports from the Gulf. The savings' average cost would be under $10/bbl: three-fourths of all residential oil and gas use is for space heating, and it is generally even cheaper to save water-heating and appliance energy than space-heating energy. Thus spending *one year's* budget for the Rapid Deployment Force[81] (meant to seize Middle Eastern oilfields) on good weatherization programs could more than eliminate U.S. oil imports from the Middle East.[82]

New technologies offer even larger savings. For example, whereas the hot-water-system improvements assumed by Watson reduce input fuel by only ~42 percent, a fuller retrofit package[83] would save ~65 percent (~0.4 MMB/D of oil and gas nationwide) and cost less than $2 per barrel-equivalent saved. Similarly, in building-shell retrofits, "superwindows" now on the market offer insulating values in the R-10 to R-12 range[84]– better insulated than most people's walls. They achieve this performance by various mixtures of spectrally selective coatings or suspended films and heavy-gas fillings, In most U.S. climates, windows better than ~R-5 can yield a net winter heat gain even facing due north. Spectrally selective windows also reject summer heat, reducing cooling loads, and greatly increase comfort year-round. They look like double glazing, weigh about the same, and cost so little extra that their marginal cost is typically recovered in about two years. When used throughout the United States, they will save at least as much oil and gas energy as Alaska now provides, Over a shorter than likely twenty-year lifetime, they save frostbelt heating energy at a cost equivalent to about $2-3 per barrel. Since normal weatherization does not include reglazing, nearly all of that saving is in addition to the weatherization savings projected above.

Industrial Oil Savings

Less is known about saving oil in industry than in vehicles or buildings, because the sector is so heterogeneous. Moreover, of the 7.9 q of petroleum used by industry in 1986, 42 percent, or 3.33 q, was used not as a fuel but as a raw material feedstock.[85] In addition, 0.47 q, or 2.8 percent, of natural gas was used as a feedstock, chiefly for plastics and nitrogen fertilizers. Nonfuel use of oil and gas has fallen steadily, by a total of 19 percent and 22 percent respectively, since 1980, largely through more efficient production processes and uses: For example, very efficient processes for making high-density polymers permit plastic bags to be made stronger *and* severalfold thinner, needing less hydrocarbon input per bag. Potential future savings of feedstocks are more complex and possibly larger than in fuel uses, since they embrace not only continued process improvements but also reduced end-use of the product itself: fewer road repairs resulting from lighter (more efficient) vehicles,[86] less plastic packaging, recyclable polymers, and innovations from materials science.

Of the 4.57 q of oil and 5.90 q of gas used as fuel in industry in 1986, most is fungible between these two fuels[87] and a substantial fraction can be saved through both conventional and innovative technologies.[88] While data on which to base a sound estimate of the untapped savings potential are sparse, SERI's analysis *A New Prosperity* suggested that a 1977-2000 primary-energy intensity reduction of ~30 percent [89] could be readily and cost-effectively achieved. Many analysts scoffed at this supposedly oversanguine projection. In fact, however, that 30 percent reduction *was actually achieved* by 1985.[90] Yet most U.S. industrial energy managers say they are still far from exhausting savings that pay back in two to three years–far shorter than any frontier oil venture.

Further encouragement can be drawn from a detailed demonstration that Swedish industry–the world's most fuel efficient[91] to start with–could cost-effectively save ~50 percent of its 1975 fuel use per unit output by using the best available 1980 technologies, or ~60-65 percent by using more advanced technologies now entering the market.[92] It therefore appears conservative to expect *another* 20 percent intensity reduction in U.S. industry by 2000. If the 1977-1985 rate of U.S. industrial savings were simply sustained, that 20 percent additional saving would be achieved by about 1993.

Utility Oil Savings

The recently merged U.S. Committee for Energy Awareness/Atomic Industrial Forum and allied lobbying efforts have been spending more than $25 million per year trying to blur the distinction between electricity and oil, and between past oil savings and the potential to repeat them, so as to imply that building more coal or nuclear power stations is vital to displacing imported oil in the future. As was shown earlier, however, building such plants has in fact made only a small contribution, at enormous cost,[93] to total U.S. supply expansion. Future oil-displacing potential is even more limited. During 1984-1986, an average of only 5.84 percent of U.S. electricity was made from oil, and only 4.06 percent of all the oil consumed made electricity (down from 10.1 percent and 16.9 percent respectively in 1973). Outside a few limited regions, oil and electricity therefore have almost nothing to do with each other. Indeed, since such a small part of national utility fuel is oil, and only

26 percent of the average 1985 retail electric bill was for fuel (the remainder being for fixed costs, nonfuel operations and maintenance [O & M], and grid losses), doubling the oil price would directly increase the average U.S. retail rate[94] by only ~0.1¢ /kwh, or ~1.5 percent.

More power plants would therefore be virtually irrelevant to the oil problem– except that their vast cost would *slow down* investments in effective oil savings. Every dollar spent on power plants cannot be spent on other measures (such as more-efficient cars) that would save more oil, faster, cheaper. In terms of opportunity cost, power plant investments thus retard oil displacement. A great deal of that retardation has already occurred as a direct result of the 1970's ~$270 billion investment in unneeded electric capacity and its ~$30 billion in annual federal subsidies. Had policymakers resisted the siren song of the power plant builders and allocated a fraction as much money to fast, cheap oil savings, the United States would probably not be importing oil in 1988. Indeed, so extravagant was the misdirected power plant-building rush that at least 27 percent of the nuclear plants built since 1973 have displaced not oil but coal, the most abundant fuel in the United States.

Without the 1973-1986 coal and nuclear expansion, 1986 oil imports, being nearly offset by oil savings elsewhere, would have risen by at most 5 percent (generously assuming that the nine-tenths of the savings that were in the form of residual oil would in fact have been replaced by new oil imports). This is not to denigrate the substantial oil savings achieved by this substitution–only to say that it would have been achieved faster, at about 1 percent of the cost, by saving the oil-fired electricity instead, tapping only a fourth of electrical efficiency's 1973 potential.[95] Nonetheless, during 1984-1986, electric utilities did still burn an average of 1.2 q/y of oil (~93% heavy, mostly residual, oil) in steamraising plants. Three major categories of oil-saving opportunities that do merit attention are available to reduce or eliminate this use.

First, it is often more efficient, both economically and thermodynamically, to burn fuel (of whatever kind) in cogeneration, yielding both electricity and useful heat, than in two separate boilers, one for process steam or heat and the other for electrical generation. Conversion to cogeneration can often more than double system efficiency, halving the consumption of fuel per unit of total work done. Such opportunities are now available and often attractive, not only in process industries, but also in commercial buildings ranging from hotels and restaurants to carwashes and laundromats. Packaged gas-fired cogeneration apparatus is available down to the tens-of-kw and even the kw range and is being increasingly applied even at the scale of single apartment buildings.

Second, on-site combined cycles, and new generating technologies such as steam-injected gas turbines and other advanced power cycles, now permit low capital cost, short lead time devices like combustion turbines to be so modified as to match or surpass the thermal efficiency of costly, elaborate supercritical steam plants. As such cycles are increasingly retrofitted into existing oil- and gas-burning apparatus, savings often approaching a factor of two can be achieved at very low cost,

Third, and most important, the modest amounts of oil and gas still burned in power plants– and, for that matter, most of the coal and all of the uranium too– can be cost-effectively displaced by new technologies that save electricity at the point of use, more cheaply than utilities can make it.[96] An astounding range of new technologies, many less than a year old, can wring several times as much work out of the electricity used in 1988, yet deliver unchanged or improved services. Superefficient lights, motors, appliances, and building components can together, if fully used in existing U.S. buildings and industries, save about three-fourths of all electricity now used, at an average cost far below that of just operating a typical coal-fired or nuclear power plant, even if building it cost nothing.[97] Since reduced demand normally causes utility dispatchers to back out first those plants that cost the most to run, and since those plants normally burn oil and gas,[98] it appears that capturing even a small fraction of the end-use electric efficiency potential would suffice to displace virtually all the oil- and gas-fired capacity now operating.[99]

A host of innovative, mainly market-oriented ways to finance and deliver the new hardware to customers is also being proven in practice. In fact, if the whole United States saved electricity as cheaply and quickly as Southern California Edison Company's customers have consistently done in recent years, the nation's long-term power needs would decline by at least 40 gw per year, equivalent to ~8.5 percent of present peak load per year. About four-and-a-half years' worth of such savings would back out all ~181 gigawatts (gw) of oil- and/or gas-fired capacity existing in 1987,[100] much of which is already idle anyway. The utilities' average cost of achieving those savings would be one or two-tenths of a cent per kwh saved– roughly a hundredth the cost of electricity from a new central power station, and equivalent in heat content to about $2-3 a barrel.

Combined Oil-Saving Potential

The opportunities just described for each sector do not lend themselves to easy summary. In very round numbers, however, potential oil savings achievable by the year 2000 (by purely technical means, not counting gas savings or oil-gas substitutions, and assuming SERI's high levels of services to be provided) are on the order of:

- 3.5-7.5 q/y in transportation[101]
- 1.2 q/y by unambitious measures (Watson's assumptions) in buildings[102]
- Essentially all of utilities' present 1.2 q/y of thermal plant oil use
- At least 0.9 q/y in industrial fuel use
- Probably at least 0.8 q/y in feedstock use

This totals about 7.6-11.6 q/y. That is 24-36 percent of total 1986 oil use– a shrinkage of one-fourth to one-third in total oil use despite average real GNP growth of 2.65 percent/y for the rest of the century (slightly faster than the average of 2.51 percent for 1973-1986). This annual oil saving by 2000 would be equivalent to about thirteen to twenty times the average 1984-1986 U.S. annual imports from the Gulf. And it is well within DOE's often overlooked estimate[103] that 10-25 q/y of energy in all forms could be cost-effectively saved in 2000 by fully using current and expected technologies.

Even that enormous saving greatly understates the long-term potential once capital stocks are retrofitted or replaced, and once gas (or alternative renewable and nonrenewable fuels) is more fully substituted. An idea of just the long-term efficiency (not substitution) potential can be gained by asking how much oil would be saved once the technical improvements noted earlier have been fully applied: say, 80-mpg cars, 50-mpg light trucks (big enough for a lot of heavy hauling), 40 percent savings in heavy trucks, buses, and trains, 50 percent in ships and aircraft, another 20 percent in industrial fuel and feedstock use, ~100 percent in utility steam plant use, and 75 percent in buildings.[104] Based on 1986 use patterns, those savings would add up to 17.1 q/y, or 53 percent of total 1986 oil use– and that is before substitutions. Just displacing the remaining industrial and building use, initially by gas for convenience (using the gas separately saved by similar efficiency gains in industry and buildings– so far we have counted only their oil savings), would save an additional 7/0 q/y or 22 percent of 1986 gas use. This would reduce total U.S. oil use to 8/1 q, or 25 percent of its present level. All of these savings would be economically very attractive at 1987 fuel prices. None would require any technology not already demonstrated and commercially available or in advanced preproduction testing. And U.S. oil use reduced by three-fourths could be entirely provided by less than half of recent domestic output, without even using alternative liquid fuels at all.

Though these data hardly suffice to construct an elaborate "supply curve" of potential oil savings, the approximate costs indicated earlier can be mentioned as indicative:

- If Volvo's cost estimates for putting its LCP-2000 prototype into production are accurate (namely, a marginal cost of approximately zero), and if comparable cost and (correspondingly reduced to, say, 55 mpg) performance are transferable, as seems plausible, to light trucks, then the steady-state saving of such a fleet in the year 2000, namely[105] 4.43 q/y for cars + 1.84 q/y for light trucks = 6.27 q/y, would have a marginal cost of approximately zero. Saving a bit more might cost a bit more.
- Since airlines and trucking firms have been pursuing the efficiency gains described earlier as vigorously as their capital constraints permitted, under the range of oil prices prevalent from 1978 to 1988, it seems reasonable to suppose that the average cost of such measures is easily competitive with those empirical fuel prices, and probably under ~$10/bbl. More empirical data on this are needed.
- Since SERI showed that 1979 technologies could save 50 percent of fueled space-heating energy through building-shell improvements at an average cost of $10/bbl, Watson's comparable 55 percent savings including water-heating (where a ~65 percent saving can cost only about $2/bbl) can be reasonably assumed to fall within the same price range. In fact, many of Watson's measures, especially the more efficient replacement furnaces, have a simple payback less than five years at present fuel prices, meaning that their equivalent oil price is about $4/bbl (or $6/bbl discounted at 5 percent/y real rate) over a twenty-year life. These savings cost essentially the same for natural gas as for oil.
- We have already cited analyses showing in detail how to save about three times as much electricity as all oil- and gas-fired power plants now make (in 1986, 15 percent of total electric output), at zero net cost to society.
- It is commonly observed by industrial energy managers that the savings that they have achieved since 1973, and will continue to achieve for at least the decade of the 1990s as available capital permits, typically offer simple paybacks under three years, Conservatively assuming that incremental savings of oil or gas will instead yield only a four-year payback at average 1984 industrial energy prices ($6.3/10^6 Btu), but will last for the normal industrial equipment lifetime of twenty years, a four-year payback corresponds to an equivalent cost of saved energy (discounting the value of future savings at 5 percent/y real) of about $2.0/10^6 Btu or $10.7/ bbl. It seems very likely that the *average* cost of such measures will be substantially lower. The same appears to be true of industrial savings in feedstocks.

These costs range from roughly zero to roughly $10/bbl. Many probably fall within, often toward the low end of, the range in between. It seems mathematically inescapable that the weighted-average price of all the measures needed to add up to even the largest oil savings described above, including those achieved by saving gas and using the saved gas to displace oil, would probably be less than $10/bbl (1986 $)– to save about three-fourths of all oil now used.

What Do Such Big Oil Savings Mean?

However such efficiency potential is assessed, it is clear that capturing far less than all of it would stretch economically and environmentally acceptable domestic oil and gas resources for very many decades beyond the time horizon commonly assumed. If, in addition, some level of imports (safeguarded by suitable diversification and stockpiling such as have already occurred) were considered tolerable as a bridge to a sustainable liquid-fuel system, the domestic oil depletion, whether economic or geological, could be postponed indefinitely. The domestic petroleum era would then last not for a few more decades but for at least a few more *centuries*.

Moreover, reducing the sense of urgency in exploration and development of new oilfields could undoubtedly yield technologies that work better and cost less. Thus, by asking its engineers to minimize cost while accepting slower construction, rather than to minimize construction time with virtually no regard to cost, Shell recently cut the total development cost of its Kittiwake field in difficult North Sea conditions by an unexpected 40 percent– from $20 to $12 a barrel. How many other such opportunities have the energy industries missed by being in too much hurry? Better oil technologies do not just save money; they effectively shift the supply curve so as to expand the economically exploitable reserves, thus buying more time. But an even more critical, longer-term virtue of this approach is that it helps buy the time to put in place the infrastructure needed for life *beyond* oil.

This is not to explore the rich menu of renewable liquid-fuel options, particularly those based on sustainably grown biofuels that contribute no $C0_2$ to threaten the earth's climatic stability[106] nor acid gas to threaten its biological productivity. That menu already contains so many combinations of cultural practice, feedstock, conversion process, fuel product, and end-use device that most of the more interesting possibilities have not even been explored yet. Technologists need the time to do so thoughtfully, and probably, given the long logistical lead times of deployment, a set of incentives driven by a social rather than a market discount rate.

Efficient use of oil buys the time needed to choose and use a diverse range of renewable liquids for transport; to displace most if not all oil uses in other sectors; and to reduce transport fuels to levels probably not requiring fossil fuels or special fuel crops, and probably consistent, given careful management, with ecological sustainability. As we stated in the recent *Atlantic* article cited at the start of this chapter:

> The efficient use of oil can also buy time for the decades-long switch to the renewable sources which, one way or another, we'll adopt as oil becomes too costly. This transition won't be quick or cheap, but that's all the more reason for getting started now– before the cheap oil, and the cheap money made from it, are gone. Already, American oil is becoming costlier than others'oil; and the faster the oil is used, the sooner those other oil-supplying nations in their turn will find their oil becoming costlier than OPEC's huge reserves. The problem that we have now, others will have later, although Saudi Arabia (according to our present knowledge of petroleum geology) will have it last of all.
>
> The short-term oil savings and diversification in our sources of oil extraction that have resulted from the past two oil shocks now offer a unique opportunity: roughly a two-decade-long respite (longer if exploration of little-known areas is unexpectedly successful, shorter if federal policy continues to stifle gains in efficiency) from Middle Eastern dominance of global oil supply. If this interval is frittered away, it could end with the United States, its alternative options expired, needing Middle Eastern oil more than ever. If, instead, we increase our oil efficiency and make sensible use of diverse alternative fuels, this grace period could expire on a United States that no longer substantially depends on oil from the Middle East or anywhere else outside our borders. Without efficient cars, no liquid-fuel future makes sense for long. With efficient cars, alcohols and other liquid fuels made from natural gas and sustainably grown biofuels– abundant or even inexhaustible resources, whose use poses little or no risk to the world's climate– can do the job at reasonable cost.

The basic priorities for oil investment remain the same in general form as when we compared in 1983 five ways to invest $100,000 to save oil:[107]

- Catalyze a program of door-to-door citizen action to weatherize the worst buildings, as Fitchburg, Massachusetts, did in 1979, and as dozens of towns have done since. Experience shows that over the first ten years, the investment of $100,000 in such a program can save 170,000 barrels of crude oil, at about $0.60 a barrel.
- Pay the extra cost (at the highest published estimate) of making forty-four cars achieve 60 mpg. The first decade's savings: 5,800 barrels at about $17 a barrel.[108]

- Buy about 3,000 barrels of foreign oil, put it in a hole in the ground, and call it a "strategic petroleum reserve." After ten years, the oil may be available, but the storage and carrying charges– probably between $50 and $70 a barrel– will be unrecoverable.
- Buy a small piece of an oil-shale plant. After ten years, it will have produced nothing. After that, if it works, it will produce up to 9,000 barrels of synthetic oil per decade; probably retailing at between $70 and $120 a barrel, in 1982 dollars.
- Buy a tiny piece of the Clinch River Breeder Reactor. After ten years, it will still be under construction. After that, if it works, the $100,000 investment will yield up to 500 "barrels" of energy (as electricity) per decade, retailing at over $370 a barrel, in 1982 dollars, and probably uncompetitive even with roof-mounted photovoltaic cells.

The Clinch River Breeder was finally cancelled, but its successors live on in enormously costly civil and military fission and fusion programs that leave mere budgetary crumbs for efficiency R & D. To this day, the U.S. government, and too much of the private sector, continues its stampede to pursue energy options (preferably at taxpayers' expense) in precisely the reverse order: Worst buys first.

Today, however, it is becoming ever clearer that trying to buy more efficiency *and* more supply, because we cannot make up our minds, is a dangerous diversion. Strong efficiency gains are sufficient to stretch domestic reserves through the transition to the era after oil. They are so many times larger than what might be obtained from grandiose supply expansions (ANWR, currently unleased offshore continental shelf, et cetera) that the latter are trivial by comparison.

Moreover, not only does the United States not need both kinds of options, but it cannot afford both, and they compete for scarce resources. Every dollar spent drilling in frontier areas, with high risks of dry holes and with finding and lifting costs well above $10/bbl, is a dollar *not* spent on drilling in cars and attics, with zero dry-hole risks and with finding and lifting costs well below $10/bbl. These options are sometimes claimed not to be mutually exclusive or even competitive as alternative ways to allocate resources. Logically, of course, there is no *guarantee* that money not spent on supply will be spent instead on efficiency, but it is equally true that money spent on supply *cannot* be spent on efficiency. From a marginalist economic perspective, the two investment alternatives should and must be compared as if their costs were fungible. The past decade's rapid shift of investment from central power plants to efficiency and decentralized plants, to the tune of more than $100 billion in commitments during 1981-1984 alone, bespeaks the capital market's flexibility in doing just that. Indeed, a major lesson of the recent and unhappy boom-bust experience in most sectors of the energy industries is that trying to get both supply expansions *and* efficiency improvements risks getting neither–or, as lately, *succeeding* in getting both and hence bankrupting the supply enterprises, which *need* new demand to pay for new supply.

This is shown most clearly by the electric utility industry's recent behavior. Since 1973 the United States has spent some $200 billion (plus at least $100 billion in federal subsidies) building unneeded power plants. Today, many of the overbuilt utilities are mistakenly trying to recover their costs by ordering their efficiency staffs to market more electricity instead. The Electric Power Research Institute estimated that these "strategic marketing" programs will create by 2000 some 35 gw of new *on*-peak demand.[109] Thus, for many firms, supply investments did not merely divert resources from efficiency, but have now abandoned neutrality and become a positive enemy of efficiency. Nor is the damage confined to the electric sector: ~$300+ billion is so large an overinvestment, compared with the marginal cost of saving oil, that it is no exaggeration to say that the United States imports oil today *because* it bought needless power plants *instead* of oil efficiency.

Likewise for the oil sector itself, spending a lot of money on drilling in a largely drilled-out province can guarantee– by sunk costs if it fails and by skewed incentives to boost demand if it succeeds–that the efficiency potential will be realized too little and too late. For time is of the essence. *Promptly* becoming very efficient in using oil could reduce or (if desired) eliminate imports *and* fuel the decades-long transition to alternative transport fuels. But the domestic reserves that, if used so prudently, could bridge the country to beyond oil will instead be burned if the efficiency gains needed to preserve them are not achieved both strongly and quickly. The United States must pick what works and get on with it. This is the predicament and the peril. It is as if, crossing a wooden bridge over a chasm, we noticed its girders were catching on fire, and instead of damping down the flames and proceeding briskly across the bridge while it was still sound, we foolishly returned to the near bank (or lounged on the middle of the bridge itself) to warm ourselves by the bonfire– until the bridge crashed in ruins.

In this race against time, it is rapidly growing too late for dithering: Bad buys on the supply side are foreclosing good buys on the demand side. The opportunity cost of the bad buys is depleting domestic oil before its replacement is installed. If we did not know how to do any better, such failure might be a forgivable result of ignorance. Since we do know, it would be an unprecedented tragedy, a grave threat to U.S. security, and quite unnecessary.

Oil Efficiency: A Key to Real Security

The national security argument for drilling for more oil, or for projecting military force to induce others to part with their oil, has been made for so long that it seems to have become the last refuge of scoundrels. But it is too important an argument to be cheapened by being applied where it does not fit. "Energy security" means more than just an unbroken line of tankers bringing oil from halfway around the world. It embraces at least six goals:

- Maintaining reliable access to affordable energy for all nations' development
- Preventing conflict over fuel-rich regions like the Gulf
- Making domestic energy systems resilient against accidental or deliberate disruption
- Abating CO_2 emissions, which might threaten global climate
- Controlling acid-gas emissions, which can damage forests, lakes, and other resources
- Inhibiting the further spread of nuclear bombs

Different ways of seeking to enhance energy security can merely trade off these problems against each other or can help to solve all of them at once; can increase or decrease economic costs; and can worsen or lessen environmental and social impacts. It is often said that if one is not going to burn large amounts of Middle Eastern oil, then, because natural gas is quite limited, one must instead burn equally large amounts of coal or uranium. Since coal makes CO_2 and acid rain, whereas uranium makes bombs, this is a singularly nasty choice of evils. But efficient energy use– the "fifth fuel– has already gone a long way toward solving all six energy/security problems simultaneously. And far from costing extra, it costs far *less* than burning the oil, coal, or uranium. The resulting "energy-security insurance policy" thus bears a negative premium.

Some of efficiency's contributions to real security are obvious enough. With reference to the first goal, for example, efficiency stretches world oil resources and softens price, leaving more oil for others at more affordable prices. Efficiency technologies are themselves more accessible to developing countries than are many supply technologies, though less assiduously promoted by vendors and aid agencies, because efficiency has relatively low capital cost, small scale, modularity, and high velocity of cash flow (owing to its short lead time and fast payback). If offered the opportunity, developing countries that are building their infrastructure from scratch could become energy efficient *faster* than we in the West, who have trillions of dollars' worth of obsolete capital stocks to replace or retrofit.

As for the second goal–avoiding conflict–efficiency is accessible to all, not restricted to occupants of mineral-rich territories. Efficiency, systematically harnessed by a few major countries, can go a long way toward making the Gulf's perilous concentration of oil resources simply *irrelevant* to human affairs.[110]

The third goal–making domestic energy systems resilient–is one of the most important and least understood.[111] It is not commonly realized, for example, that a handful of people could cut off three-quarters of the oil and gas supplies to the eastern United States, for upward of a year, in one evening's work, without even leaving Louisiana. (Electric grids are even more fragile than that.) In 1988 Secretary Hodel sought to drill for oil in the Arctic National Wildlife Refuge so as to prolong the life of the Trans-Alaska Pipeline System (TAPS). From a security perspective, that would be a very bad idea. TAPS runs for 798 miles through some of the roughest country in the world, yet is accessible for most of its length by road or floatplane. It has already been repeatedly, if incompetently, bombed and shot at by people who apparently sought theater, not real damage. The army has declared TAPS indefensible. In 1977, one of its pumping stations was blown up by a technician's mistake; had it been a northerly rather than the least important (most southerly) station, and in the winter, the nation could have been treated to the spectacle of 800 miles of hot oil slowly congealing into the world's largest Chapstick.

That frail lifeline is how the United States currently delivers in 1987 24 percent of all the crude oil it lifts and 15 percent of all its refinery inputs: 83 percent more oil than the United States imported in 1987 from the Gulf. There are many alternative routes for Gulf oil, but none for North Slope oil, Gulf oil has proven surprisingly hard to disrupt: Kharg Island continued to ship oil amid heavy air attacks. Yet TAPS's pumping stations, or the "Hollywood and Vine" manifold of large pipes at its north end, or certain terminal facilities at its south end, could be disabled for a year or more (the lead time to remake some of the pipe is several years) by a few kilos of well-placed *plastique*. Because of remoteness, weather, and specialized facilities, the damage could also be far harder to mend, and easier to repeat once mended, than damage to non-Arctic oil facilities. Continued dependence on TAPS, therefore, puts far more of U.S. oil supplies at risk to one simple, unattributable, and unstoppable act by a lone terrorist than could possibly be cut off by an all-out war in the Strait of Hormuz.

When TAPS was designed and built, its engineers apparently assumed a "technological paradise" in which everything worked according to the blueprints, and terrorism was the stuff of novels. If Americans ever lived in such a world, they do no longer. Drilling in the Arctic National Wildlife Refuge for still more oil, so as to prolong dependence on TAPS, would– on the less-than-19 percent chance it succeeded[112]– perpetuate one of the gravest *threats* to U.S. national security.

There is now abundant evidence that resilient energy systems, in which major failures of supply are no longer possible, cannot be achieved by hauling fuels from ever more remote places. True energy security comes from making supplies more diverse, dispersed, inherently uninterruptable, and very efficiently used. Efficient use lets alternative supplies meet a bigger fraction of needs and makes existing stockpiles last long enough to mend what is broken or to improvise new supplies. (Thus, a 60-mpg car fleet could run on its normal in-tank inventories, if the tanks were not downsized, for a month without refueling, and on the "pipeline inventory" of the oil-supply system for about a year. In contrast, a modern refinery deprived of its feed is often out of business in a few *days*.) Far from costing more, this approach actually *reduces* energy costs. It is also the direction in which the market is already taking us.

There is a growing consensus that a less contingent, more inevitable kind of security threat looms in the coming decades: serious and probably irreversible changes in the earth's climate, caused by the CO_2 released by burning fossil fuels. In an earlier analysis for the German Federal Environmental Agency,[113] we showed that very efficient use of energy is *the only practical, large-scale option* for averting this threat. Other authors have since come to similar conclusions.[114] Here again, efficiency's security benefits are better than free.

A similar "no losers" approach is available for the acid rain from power plants. Rather than raising electric rates to put diapers on dirty coal plants, utilities can employ a variety of proven methods to help customers use electricity far more efficiently. The utilities can then burn less coal and emit less sulfur (preferably backing out the dirtiest plants first), but mainly they will save a great deal of money, because efficiency costs less than coal. They can then use part of the money to clean up the remaining plants and the rest to lower their rates to more competitive levels. At least three states–Wisconsin, Minnesota, and New York– already officially recognize the validity of this approach. A recent analysis[115] for the Midwestern (ECAR) region, which is responsible for a third of power plant acid-gas emissions, assumed a potential to save only 26 percent of electricity now used– too low by perhaps threefold– and unrealistically high costs for those savings. Despite these strong conservatisms, the analysts found that using electric efficiency to finance a 55 percent acid-gas reduction would cut that reduction's present-valued cost (depending on the exact investments chosen) from $3.6-8.4 billion to *minus* $3.7-7.7 billion. Simultaneously abating much of the CO_2 emissions from the same plants would be a free bonus.

Another serious threat to national and global security is nuclear proliferation. We have shown elsewhere[116] that the main technical driving force behind the spread of nuclear bombs is "civilian" nuclear power programs. They provide the materials, skills, equipment, data, and above all the innocent "cover" for bomb programs. But in a world without nuclear commerce, all these ingredients, though obtainable on the black market, would be harder to get, more conspicuous to try to get, and politically far costlier to be caught trying to get– because for the first time the reason for wanting them would be *unambiguously military*. This would not make proliferation impossible, but would make it far more difficult: for most *n*th countries of concern, prohibitively difficult.

The global collapse of the nuclear enterprise, if recognized for what it is and capitalized on with programs to help developing countries meet their legitimate energy service needs, is thus a timely opportunity to inhibit proliferation. That collapse has no precedent in industrial history: Nuclear capacity in 2000 will be at most 6-8 percent in industrialized countries, and 2-3 percent in developing countries,[117] of the levels officially forecast in the early 1970s. That this double-edged venture is dying of an incurable attack of market forces is the best possible news for world peace, and incidentally (by the resources it frees up) good news for faster oil displacement too. Energy efficiency–by both saving electricity (which displaces reactors) and displacing directly used oil (a common argument for building reactors)– is the key to *un*spreading the bomb.

Changing the World

Listing some of the specific security benefits of energy efficiency is usefully concrete, but risks overlooking a far wider range and perhaps more important indirect benefits. It is sobering to reflect, therefore, on how *the whole world* could have been made more secure if the past decade's improvements in U.S. energy efficiency had instead been undertaken a generation earlier. In 1951, for example, President Harry Truman's Paley Commission called for a major effort on energy efficiency and renewables. Had its recommendations been followed:

- The United States would not then have entered the world oil market in the early 1970s as a major importer. OPEC would not have gained most of the market leverage that underpinned the 1973-1974 embargo and the accompanying price increases, global recession, and worldwide monetary inflation.

- Developing countries would have been less squeezed by the world oil market and would be better able to support themselves today.
- The enormous transfer of wealth to the Middle East would have been reduced by both the lower price and the reduced consumption of oil. The dangerous Middle East arms race, with its spillover into terrorism, might therefore have been drastically curtailed. The Iran-Iraq war, had it occurred, would have been nowhere near its actual level of violence. Israel would probably be more secure and would require correspondingly less U.S. assistance.
- It is questionable whether Islamic fundamentalism, accelerated by rapid and culturally insensitive industrialization, would have emerged in significant force at such speed; whether its threat on the flanks of the Soviet Union would have been seen to justify the invasion of Afghanistan; and, just conceivably, whether President Jimmy Carter, absent the Iranian hostage crisis, might not have been reelected, helping to avoid the voodoo-economics calamity.
- Oil choke points like the Horn of Africa and Strait of Hormuz would be seen as less vital U.S. interests, and the military missions associated with maintaining freedom of passage in such areas would be correspondingly downgraded.
- Much of the terrorism of the 1980s might have been curtailed, owing to reduced motivation, financial support, and weaponry.
- The recycling of petrodollars via Western banks' force-fed loans to developing countries would probably have been diminished, and with it, the Third World debt crisis, with its accompanying risks to the political stability of those countries and the financial stability of the world.
- The loans' invitations to large-scale corruption, militarization, and inappropriate forms of development by less developed country (LDC) governments would have been correspondingly reduced: The multibillion-dollar looting by Ferdinand Marcos and Sese Seko Mobutu would have been less likely to occur, leaving such nations as the Philippines and Zaire at least potentially fairly healthy.
- The Mexican economy would have had an opportunity to pursue a more resilient development strategy rather than one precariously perched on high oil prices, This would have had important implications for, say, U.S. immigration policy. In general, oil exporters would have gotten the benefits of steady, sustainable development without the costs of boom-and-bust instability. Houston would have enjoyed slower but steady growth, while frontier energy boomtowns would probably not have experienced their current economic crash because they would not have become overgrown in the first place.

Britain would have depleted its North Sea reserves far more slowly, providing a softer economic landing as oil output declined.

- U.S. competitiveness, balance of trade, net wealth, fiscal integrity, and energy security might have been markedly improved. The pervasive economic benefits of low real oil prices, which proved so valuable (outside the oil patch) in 1986, would probably have occurred *throughout* the 1974-1987 period, without the disruption which their exceptional occurrence brought *inside* the oil patch.
- Hundreds of billions of dollars' investments in uneconomic expansions of energy supply would have been avoided, along with their side effects at home and abroad, ranging from acid rain to nuclear proliferation to insolvent utilities.
- With fewer pressures to earn oil-buying dollars by exports, pressures on U.S. farm communities, topsoil, and groundwater could have been reduced, and the vast and destabilizing exports of advanced weaponry by the United States, France, and other countries, might have been more readily controlled.

Such speculation reinforces the decade-old joke that the best form of Middle Eastern arms control might be U.S. roof insulation. Of course, other, unforeseen, thoroughly disagreeable events might, in this alternative scenario, have replaced those avoided. No one can guarantee that on the whole the alternative outcomes would have been preferable to what has actually occurred. But the outcomes are clearly so *different* in their security implications that this thought experiment at least merits further pursuit (and implementation, lest we have to relearn these lessons the hard way over the *next* decade or two). The benefits of energy efficiency, pursued to their logical conclusions, may well prove to be far more pervasive and interactive than anyone has imagined.

Conclusions

For an oil company seeking to chart a course through the turbulence of the coming decades, these relationships by which energy efficiency fosters security are not theoretical niceties; they define the future business environment. And they do so in ways less trivial than merely saying one cannot sell oil to people who have been blown up, Both acid rain and CO_2 constitute serious long-term (and, in some places, not so long term) threats to customers' ability and willingness to continue to buy fossil fuels. Lack of affordable energy services stifles the sustainable global development on which energy companies' markets ultimately depend. International tensions over places like the Gulf threaten both the demand for and the supply of energy, and inject geopolitical uncertainties that defeat sound planning.

Economically, the energy industries have much housecleaning to do to ensure their own solvency and indeed their long-term survival. Those who claim to live by the market are often among the last to appreciate its verdicts. The emerging energy service marketplace– where oil and gas must compare not only with other fuels but also with more efficient provision of mobility, comfort, light, torque, and other desired services at least cost to the customer– has profound consequences, which have barely begun to sink into the consciousness of many chief executive officers (CEOs), and which demand difficult adaptations in corporate missions, career goals, and personal identities. Engineers and managers who have spent their lives building multibillion-dollar projects may feel less emotionally fulfilled by doing millions of small things instead. Many managers have gotten into the bad habit of looking at the top line instead of the bottom line, seeking bigger sales and revenues instead of seeking to cut costs more than to increase revenues. Further, a generation of industry leaders grew up in a fat era when cost discipline was lost, both upstream and downstream rents were plentiful, and sloppy habits would not predictably attract competitive penalties. Yet the competitive forces that have so lastingly softened demand for oil and gas have barely begun to express their full market potential. The energy savings that have turned the industry on its head have only started to scratch the surface of what is now available and cost effective.

Those energy companies that are first to internalize the full meaning of the competitive energy service marketplace will make more money at less risk by selling less energy, but more and cheaper energy services. In so doing, because sustainability is indivisible, they will contribute signally to both the world’s security and their own.

Notes

1. The authors are grateful to the many reviewers of the draft of this chapter, both within and outside the oil industry, for their insightful criticisms and suggestions, but the authors are solely responsible for the data and opinions given here.

2. “Best buys” could be defined either in the narrowest terms of engineering costs and market prices, or more widely to include externalities, This chapter adopts the former convention but then qualitatively discusses the latter. The California Energy Commission and several public-interest groups hope to develop such an analysis during 1988-1989, ideally deriving a “supply curve” of all salient ways to save or get oil, arranged in order of increasing cost.

3. These are analyzed in A. B. and L. H. Lovins, “The Avoidable Oil Crisis,” *Atlantic*, December 1987, pp. 22-30. See also subsequent correspondence, ibid., April 1988, pp. 10-11, and June 1988, pp. 10-11.

4. This term is due to David R. Brower.

5. A. B. and L. H. Lovins, *Atlantic*, op. cit. supra. Dr. Earl Ravenal, who provided the FY1985 analysis of Gulf military costs ($47 billion) used here, has not yet updated his results for the following two fiscal years but hopes to do so for FY1987 using the expenditure data released in January 1988. Per barrel, that cost will probably be somewhat lower than the FY1985 level, owing to higher imports from the Gulf, but still several hundred dollars per barrel. It may of course be objected that if U.S. forces were not in the Gulf, they would be somewhere else and still incurring comparable costs. The primary mission of Central Command, however, is Gulf intervention; and about one-fourth of all active army and marine divisions, aircraft carriers, and fighter wings have a first-priority commitment to Central Command. If the Gulf ceased to be militarily important, a major reassessment of force requirements would obviously be in order. See T. Sabonis-Chafee, “Projecting U.S. Military Power: Extent, Cost and Alternatives in the Gulf,” September 1987 paper to Pugwash Conference (Gmunden, Austria), Rocky Mountain Institute Publication #87-23.

6. The extra cost, if any, of developing and making more efficient cars is probably far more than offset by the reduced costs of finding and providing their fuel, not to mention avoided military and environmental costs, the financing costs of associated trade and budget deficits, et cetera.

7. R. H. Williams, 31 July 1984 testimony to USHR Subcommittee on Energy and Power.

8. To their credit, many oil executives (such as Robert O. Anderson) who at the time pushed for an Energy Mobilization Board soon realized that the environmentalists who opposed it, on both substantive and procedural grounds, had thereby helped to save the industry from unprecedented disaster. See A. B. Lovins, “Is Red Tape a Code Word for Law?” *Washington Post*, 3 August 1979, op-ed.

9. It was aided, ironically, by some of the same individuals responsible for the earlier fiascos. Interior Secretary Hodel, for example, was widely regarded in the oil industry as sympathetic to its plight. His efforts to help the industry, however, might appear in a different light if it were recalled that he was trying to help the Northwest’s utilities when he designed the mid-1970s policies that led directly to the $7 billion Washington Public Power Supply System (WPPSS) default in the Northwest (after it took only two years, 1980-1982, for his prophesied electric shortages to turn into a seemingly endless glut). His emphasis on supply rather than on demand seriously harmed the very utilities he sought to help. See A. B. Lovins, “Scraping the Bottom of the Barrel,” *Wall Street Journal*, 1 May 1987, p. 21.

10. This term is analogous to the more popular and euphonious “negawatts,” which originated as a typographic error in a Colorado Public Utilities Commission PUC document. Observing that a negawatt (saved electricity) is like a megawatt, only cheaper, we popularized the term, and it is now widely used by utilities.

With reference to oil, we try to avoid the economic term “produce,” since it invites confusion between production and consumption. In physical terms, an oil company is not “producing” oil at all– ancient geological processes did that– but only digging it up and burning it.

11. Recent DOE analyses by H. R. Holt (“Boom and Bust: Chaos in Oil Prices, 1901-1987: A Statistical Analysis,” draft, 8 March 1988) showed that real oil prices since 1987 satisfy every statistical test of randomness, with no significant autocorrelation beyond -2 y. The baseline is surprisingly flat, with a real 1972-$ increase averaging only 4¢/bbl/y (in two steps, -1¢/bbl/y during 1902-1972 and +25¢/y during 1973-1986): The real price in 1987 was 2¢/bbl below the real 1901 price. Price volatility, however, has increased fivefold since 1972 in mean deviation and eighteenfold in variance.

12. These and most other U.S. energy data, throughout this chapter, are from the Energy Information Administration’s (EIA’s) *Monthly Energy Review,* September 1987, DOE/EIA-0035(87/09). That issue introduced a revised car-efficiency data series differing significantly from early data for 1970-1986.

13. That is, “If the 1976 size class shares for autos were applied to the 1987 car class fuel economies, the resulting new car mpg would be 27.7 in 1987 (just 0.4 mpg lower than the actual value).” Phil Patterson, *Periodic Transportation Energy Report 1* (DOE CE-15, 202/586-9118) 16 November 1987. This occasional newsletter is the best current data source on U. S. transportation energy use, (Patterson’s car finding, however, does not hold for light trucks: The same issue reported that 42 percent of the 5.3-mpg gain for new light trucks– a gain less than half the 10.9-mpg improvement in new cars– was due to a shift to smaller models.)

14. Marc Ross has pointed out that U.S. steel consumption per dollar of GNP is now below its 1870 level, and falling.

15. EIA’s *Annual Energy Review* 1986 showed 135.7 million passenger cars (apparently including personal light trucks and minivans) registered in 1986. At 18.32 average mpg in 1986 (*Monthly Energy Review*, op. cit.), then driving 9,625 miles per car in 1986 (ibid.) would have taken 1.85 million barrels per day (MMB/D) more at 1973’s 13.10 mpg, or slightly more counting refinery/marketing/distribution losses. In fact, however, the saving was probably greater, because the number of registered cars includes personal light trucks and vans, which started as less efficient and had more to save. (The Department of Transportation’s present standard for new light trucks is 19.5 mpg.) In 1986, Alaskan oil output was 1.87 MMB/D, while reported gross imports of Gulf crude and products totaled 0.91 MMB/D. (“Gulf” in this chapter refers to the Arab OPEC states, plus Iran, less Algeria and Libya: that is, to Saudi Arabia, Iran, Iraq, Kuwait, Qatar, and the United Arab Emirates. Over 2.0 MMB/D of their ~10 MMB/D oil exports are shipped overland, not through the Strait of Hormuz.)

16. This ratio was in excess of a hundred until the early 1980s, then fell as the relative share of renewable energy supply expansions (shown in the tables) significantly increased.

17. Strictly speaking, net busbar output of nuclear electricity converted back to steam-equivalent at the nuclear plants' heat rate, so energy consumed by in-plant machinery has been deducted.

18. Authors'analysis based on EIA data (*Monthly Energy Review*, March 1987).

19. Unpublished analysis by Charles Komanoff, summarized in *Science* 239:128 (1988). We are indebted to Komanoff also for the format of Tables 7.1 and 7.2. The comparison is actually with 1978, but reflects achievements in and after 1979, and is therefore described here (though not by Komanoff) as having occurred *during* 1979-1986 (inclusive).

20. Savings are reflected as a reduced ratio or primary energy consumption to real GNP; most of this results from technical-efficiency improvements. The savings shown in Table 7.2 are slightly different because, when "non-EIA" renewable supply is included for both the starting and the ending year of each comparison, the numerator of the energy-GNP ratio changes slightly from the original amount reported by EIA.

21. Following Komanoff (op. cit.), 1978 coal extraction is taken to be the average of 1977 and 1979 values. This smoothing avoids understating 1978 coal output as a result of that year's coal strike.

22. Nuclear power, like geothermal electricity and hydroelectric power, is stated in equivalent primary terms, based on EIAheat rates. That is, the contribution shown here is the increased output of nuclear *steam*, not electricity, which is only 31.6 percent as great, not counting grid losses.

23. "Other EIA supply" excludes wood and wood wastes, direct solar energy capture by anyone except major utilities, and several minor renewable sources: None of these is shown in the summary statistics at the front of EIA's *Annual or Monthly Energy Reviews,* although later sections show some for certain years (usually ending in 1984).

24. The total of these three contributions– savings, coal, and nuclear– exceeds 100 percent because of the balancing entry for declining oil and gas output.

25. Both EIAand other sources show hydroelectricity only as reported by utilities (for EIA, only large utilities), wholly or almost wholly generated by dams that they own. There is also, however, a considerable output from privately owned hydro dams, many of them small or low-head, but it is difficult to determine its magnitude without a risk of some double counting. DOE's *Energy Security* (March 1987), p. 206, reports "nearly 0.4" q of 1984 (primary) output from "low-head hydro," and 6.8 gw on line at the end of 1985, much of it new, but it is unclear how much of this, if any (the Gas Research Institute [GRI] says none), is included in EIA's utility-based statistics or how fully it represents private hydro output of electricity or of direct mechanical drive. As a conservatism, therefore, all non-EIAprivate-hydro and "small hydro" contributions are ignored here, although they might at least double the 1979-1986 hydroelectric growth shown here.

26. EIA actually showed 0.01 q/y of other renewable output in 1977, 1979, and 1984-1986, this consisted largely of wood and wood wastes burned *by electric utilities*. Nearly all of the wood consumption shown elsewhere by EIA,

in obscure, specialized publications (note 28 infra), was thus omitted from its widely cited summary statistics. This resulted in an understatement of ~3-4 percent in national energy use and supply–more energy than nuclear power delivers.

27. Smoothed to the average 1970-1986 capacity factor, to avoid distortion by annual runoff fluctuations. The smoothed primary outputs for 1973, 1979, and 1986, respectively 2.548, 3.062, and 3,295 q; the unsmoothed outputs used by EIA are respectively 2.86, 2.93, and 3.04 q.

28. Conservatively taken as equal in 1986 to the Gas Research Institute's estimate for *1985* (in GRI's 1986 base forecast), namely 2.653 q. That is consistent with EIA's last published estimate– 2.633 q in 1984. For 1973 and 1979, EIA's corresponding estimates of wood use were 1.528 and 2.149 q (DOE/EIA-0341[82] and [83]). GRI also referred to a substantial amount– 1.26 q in 1983, for example–of "nonwood wastes" including such nonrenewable terms as refinery offgas, coke-oven and blast-furnace gas, but also including partly or wholly renewable sewage and landfill gas, GRI believed that most or all of these waste gas streams were probably excluded by EIA too, and none was reflected here.

29. This figure is undoubtedly an underestimate. It is derived from EIA's last published estimate (0.251 q in 1984) for alcohol fuels and miscellaneous crop wastes (such as bagasse, rice hulls, cotton gin trash, pineapple waste, nut hulls, et cetera–*Annual Energy Review 1986*, p. 215) plus GRI's last published estimate for direct solar capture by nonutilities (0.040 q in 1985), less the 0.01 q counted by EIA as "other"–windpower/woodburning/photovoltaic/solar-thermal/waste-fired electric power plants owned by electric utilities. EIA provided no data on the much larger amounts of such capacity owned by others (such as the 1.4+ gw of private windfarms, which alone account for ~0.02 primary q/y), nor on nonelectric appliances of other renewable sources, such as geothermal direct heating (estimated in DOE's *Energy Security*, p. 203, at >0.0002 q). As a further conservatism, none of these figures counted any of the rapidly expanding energy recovery from municipal solid wastes, most of the energy content of which can be considered renewable.

30. Much the same is true abroad. In Japan, for example, Komanoff (personal communication, 31 March 1988) calculated that during 1978-1986, Japan's GNP grew 36 percent while primary energy consumption grew only 4 percent (compared with 19 percent and -5 percent for the United States; Japan, even though more efficient to start with, outpaced the United States by 4:3 in efficiency gains). Japanese nuclear output grew by 1.1 primary q/y, but Japanese savings grew by 5.5 q/y, a 1:5.2 ratio. Even in France, savings have outpaced nuclear expansion by severalfold; in Western Europe as a whole, by at least tenfold.

31. The ratio of annual savings gained during 1973-1986 to 1986 domestic crude oil extraction (18.35 q) is 1.43 counting only the renewables included in the EIA summary statistics; 1.37 including the fuller list of renewables; and 1.36 with hydropower smoothed. Please see note 20 supra.

32. Our effort to do so here is not particularly profound but strives for simplicity and transparency. No doubt a more detailed statistical analysis would turn up interesting new details, but at the risk of obscuring fundamentals.

33. All energy and GNPdata in these and subsequent figures are from EIA's March and September 1987 *Monthly Energy Reviews* and *Annual Energy Review 1986.* Other data are from the *Statistical Abstract of the United States* and the Commerce Department's October 1987 "Economic Indicators."

34. They disingenuously claimed that this was the result of free market behavior, not their marketing strategy. Other manufacturers operating in the same market but with different sales goals seem to have had no trouble meeting the standards.

35. The official figure is apparently secret, but an estimate in excess of $1.2 billion has been prepared from the published data by the Center for Auto Safety in Washington, D.C.

36. This assumes ~117 million cars in 1986 driven 9,625 miles, ~38 million light trucks driven 11,016 miles (1985), on-road mileage 15 percent worse than EPA mileage (DOE methodology), and 1.88 bbl crude per bbl gasoline (1986), since marginal imports are driven by light-product demand. Some unknown fraction of the reduction in annual fleet-efficiency gains, however, may also be due to the administration's 70 percent reduction in the print run of the annual "Gas Mileage Guide," so that two-thirds of new-car buyers were unable to get a copy.

37. Calculated from EIA's *Monthly Energy Review*, March 1987, p. 16.

38. That is, 3.48 additional q of petroleum would have been needed to produce the 1986 GNP at the 1984 level of oil productivity (oil-consumption/ real-GNP ratio),

39. The 1985 gain in oil productivity (3.05 percent) was nearly as fast as the average gain (3.21 percent) during 1982-1985– a relatively stable and representative period during which, however, the average real price of leaded regular gasoline *fell* by an average of 7.94 percent/y and the average real refiner acquisition cost *fell* by 10.48 percent/y.

40. The December 1987 *Monthly Energy Review*, published in March 1988, gives preliminary full-year 1987 data of 2.88 percent GNPgrowth, 1.56 percent oil-productivity growth (more than making up the 1986 decrease), and domestic oil output down 4.26 percent, yielding a 5.58 percent rise in imports, moderately close to the actual 6.03 percent.

41. DOE's 1984 estimates, from FY1987 *Energy Conservation Multi-Year Plan*, July 1985, p. 97. The numbers of vehicles are 1986 registration data from EIA's *Annual Energy Review 1986*, p. 61. DOE's March 1987 *Energy Security* gave slightly different values for an unstated year: 59 percent light vehicles, 17 percent heavy trucks, 9 percent ships and trains, 8 percent aircraft, and 7 percent "military and other." A detailed disaggregation, with comparative forecasts, was provided by M. Miller and A. Vyar, "Transportation Energy Demand from 1980 to 2010: The ANL-85N2 Forecast," Argonne National Laboratory #ANL/CNSV TM-169, August 1985. The Oak Ridge National Laboratory *Transportation Energy Data Book: Edition 9*, ORNL-6325, April 1987, gave slightly different shares for 1984: 44 percent cars, 0.1 percent motorcycles, 0.7 percent buses, 12.3 percent light trucks, 15.8 percent heavy trucks, 3.6 percent off-highway heavy vehicles (construction, mining, and farming), 72.9 percent total highway; 8 percent aircraft,

6 percent watercraft, 4 percent pipelines, 2.5 percent railways, and 3.5 percent military operations. None of these discrepancies is important to our thesis here.

42. Light trucks are in the process of rising from a fifth to a fourth as numerous as cars, and tend to average at least 4 mpg less efficient. Light trucks thus use nearly a third as much fuel in total as do passenger cars. More work is needed to improve and perhaps partly to displace trucks, since otherwise, early in the twenty-first century, trucks may come to use as much fuel as cars, Phil Patterson (*Periodic Transportation Energy Report 2*, DOE, 23 December 1987) reported that although light trucks accounted for 30.6 percent of new light vehicles in model year 1987, they were driven 15 percent more miles, average 23 percent less efficient, and (as of 1983) lasted 37 percent longer. The combined effect would be that light trucks' share of lifetime fuel use by 1987-model-year light vehicles would be *48 percent.* Fortunately, about two-thirds of light trucks' gain in market share since 1983 is from minivans (ibid, at p. 9), which in engineering terms are more like cars than like utility trucks,

43. The absolute consumption cited for trains in 1984, 0.63 q, included nearly all of what EIAreported as 0.013 q of end-use electricity, implying that trains used ~0.62 q of direct fuel– 98 percent of their total use. In contrast, Oak Ridge National Laboratory (ORNL) reported 0.52 q used by trains, of which only 92 percent was direct fuel.

44. This mode used an estimated 4.6 percent of the 1984 total end-use transportation energy (0.91 out of 19.68 q), but accounted for nearly all of the 0.52 q of natural gas used for 1984 transportation. Oil use by pipelines would be correspondingly less– about 0.4 q/y, or 2 percent of total transportation oil use.

45. EIA's *Annual Energy Review 1986*, p. 21, stated that in 1986, the Department of Defense used about 0.0236 q of motor gasoline, 0.273 of distillate and residual fuel oils (presumably including diesel fuel), and 0.708 of other petroleum products, chiefly aviation fuel. The total, 1.004 q, was 2.85 percent of national petroleum (including NGL) consumption. Arbitrarily assuming that all motor gasoline, half the distillate-and-resid category, and 90 percent of the "other" went to transportation would imply a DOD transportation fuel use of about 0.8 q, or 3.9 percent of national transportation fuel use. The 1984 "Other (incl. Military)" transportation fuel use estimated by DOE was 0.68 q.

46. T. Sabonis-Chafee, op. cit. supra (note 5). The Vietnam war was more land based than a Gulf war would probably be, and hence less fuel intensive, yet it used ~1 q/y of transportation fuels.

47. Phil Patterson, *Periodic Transportation Energy Report 3*, DOE, 12 February 1988.

48. These and later mpg ratings, unless otherwise stated, are "composite" EPA ratings weighted 55 percent city/45 percent highway. On-road mileage for gasoline-fueled cars is typically less by 10 percent city/20 percent highway. This correction is incorporated into the foreign-car mpg ratings given in this chapter. See D. L. Bleviss (Federation of American Scientists, Washington, D.C.), prepublication draft, *The New Oil Crisis and Fuel Economy Technologies: Preparing the Light Transportation Industry for the 1990's* (Westport, Conn.: Greenwood Press, 1988), Appendix.

49. Assuming that the average new car does not in fact do better than the reduced standard. In fact, in model year 1986 (1987), Ford achieved 27.0 (26.8) mpg and GM 26.6 (26.4), compared with Chrysler's 27.8 (27.6). The *average* car sold in the United States was rated at 28.2 (28.2), but only because Americans, despite restrictions on Japanese imports, bought a record 27.4 percent (29.2 percent) share of foreign cars averaging 31.6 (31.0) mpg, compared with domestic cars' 26.9 (26.7) mpg. Data from USDOT, National Highway Traffic Safety Administration (NHTSA), NEF-31, "Summary of Fuel Economy Performance…," 1 February 1988; the NHTSA contact is George Entwistle, 202/366-5303.

50. The federal government's "conditional" mean estimates of economically recoverable (at high prices) undiscovered oil in these areas are respectively 3.2 and 3.8 billion barrels. ("Conditional" means *if* economically recoverable oil is found there at all; in ANWR the probability of finding such oil is said by the Interior Department, assuming *very* high prices, to be 19 percent, and by state of Alaska geologists, who also predict about half the quantity, to be 10 percent.) The annual mean output of such a mean discovery, if it occurred, would be roughly the mean recoverable reserve divided by the field life (officially stated to be at least thirty years). But in fact, development lead times and phasing considerations would limit mean-reserve ANWR output in 2000, according to Interior, to 0.147 MMB/D, By inference, output offshore California in that time frame would probably be comparable. But 2000 would be close to the *end* of the lifetime of the car fleet bought in model years 1986-1988 and thereafter. That fleet of >110 million automobiles, getting 26 instead of 27.5 mpg and driving ~10,000 miles per year, would use an extra >0.150 MMB/D–slightly more than either area's likely output (if any) in 2000, and considerably more than their mean output in earlier years when new 1986-1988 cars would still be operating. (A barrel of gasoline is again conservatively equated here with a barrel of crude oil, although not all of a barrel of crude can in fact be refined into gasoline.)

51. For example, in a fleet consisting of 80 percent cars getting 60 mpg and 20 percent getting 10 mpg, the average is not 50 mpg but 30 mpg. This becomes intuitively clearer when one remembers that, with equal miles driven, each 10-mpg car uses as much oil as *six* 60-mpg cars do.

52. Except, apparently, to inhibit market action by reducing the information available to consumers. DOE has also largely abdicated its research role, leaving much innovation (owing to the major U.S. carmakers' short time horizon) to foreign vendors (Bleviss, op, cit., Chapter 9). It is interesting, though, that General Motors believes (Al Sobey, personal communication, 6 June 1987) that average U.S. new car efficiency, influenced by competitive forces, will continue to increase by ~1-2 percent/y for at least the rest of the twentieth century without any government action. This implies year-2000 new car averages on the order of 31-36 mpg.

53. The oil savings calculations in this and the next paragraph are by Robert K. Watson, Natural Resources Defense Council, San Francisco. They are purely technical, omitting potential savings of ~10 percent of car fuel by traffic

management, and do *not* count the (1986 US. average) requirement for 1.88 bbl of crude oil to make 1 bbl of gasoline. Since light-product demand drives imports, one should multiply all the given savings by ~1.88 to obtain crude oil savings, but this step is omitted here as a conservation except where specifically stated.

54. "Risked mean" reflects the Minerals Management Service's adjustment of how much economically recoverable oil *might* be in the ground (a computer simulated mean of 6.9 billion bbl, including 3.2 in ANWR) for the service's estimate of the likelihood of finding *none*. The price assumed by Interior in assessing what is economically recoverable from ANWR, however, is $35/bbl (1986 $) in 2000, rising to $39-61/bbl depending on which of Interior's two cited sources one adopts, and possibly rising thereafter at an unspecified rate. Such levels are far above what the oil industry apparently expects, since it is not drilling now in far cheaper areas. The federal analysts have so far provided no sensitivity test on their price assumptions– surely the first people to assume a single price forecast since the oil-shale industry. Lower prices, however, would sharply increase the minimum recoverable field size and hence the risk of finding no such field. Moreover, Interior discounts projected benefits at a risk-free real rate of only about 1 percent/y. Yet even a slightly lower price trajectory or a more reasonable discount rate would make the claimed net benefits of ANWR oil strongly negative and the risked mean reserve virtually nil. See, e.g., W. T. Georald, *Materials and Society* 11(3): 729-307 (1987) (effects of using state of Alaska's geological assumptions and post-1986 tax law). Furthermore, J. S. Young and W. S. Hauser (Bureau of Land Management [BLM] Alaska Office), "Economics of Oil and Gas Production from ANWR for the Determination of Minimum Economic Field Size," undated, ca. 1987, concluded that lowering the 1984-$ oil price from $40 to $22/bbl raises minimum economic field size in E (W) ANWR by 5.0- (4.2-) fold, from 0.41 (0.33) to 2.03 (1.39) million bbl. In contrast, Interior gave an aggregated estimate of 0.15 @ $40/bbl and 0.44 @ $33/bbl. Obviously, the steep rise in required field size at lower prices was unfavorable to Interior's case, since the probability of finding a minimum recoverable field falls sharply with its increasing size, so Interior presented no low-price option.

55. Taking all of Interior's data at face value, and risking the 3.23 billion bbl of claimed conditional reserves only with the 0.19 stated probability of finding any economically recoverable oil. On Interior's uncorrected data, however, the probability of finding at least the claimed mean amount (3.23 billion bbl) of economically recoverable oil is only 0.19 x ~0.34 = 0.065.

56, See, e.g., C. Gray and F. von Hippel, "The Fuel Economy of Light Vehicles," *Scientific American*, May 1981, pp. 48-59; TRW (McLean, VA), "Appendix–Data Base on Automobile Energy Conservation Technology," 25 September 1979; Office of Technology Assessment, *Increased Automobile Fuel Efficiency and Synthetic Fuels: Alternatives for Reducing Oil Imports* (Washington, D.C., 1982); Bleviss, op. cit., 1987.

57. Bleviss, op. cit., offered an excellent summary of the 1984-1985 market status of these and other innovations. *Popular Science,* January 1988, p. 52, reviewed a typical one, the Fiat Uno minicar's continuously variable transmission.

58. R. K. Whitford, "Fuel-Efficient Autos: Progress and Prognosis," *Annual Review of Energy* 9:375-408 (1984).

59. Bleviss, op. cit., pp. 156ff.

60. *Auto Week*, 3 August 1987, p. 6. *Popular Science*, December 1987, described a slightly different test result– 138 mpg at a steady 56 mph, while *Datafax*, October 1987, p. 12, mentioned 64 mpg city and 85 mpg at a steady but excessive 75 mph.

61. Ibid., p. 118.

62. *Statistical Abstract of the United States 1987* (Washington, D.C.: U.S. Bureau of the Census, December 1986), p. 590, The ORNL *Transportation Energy Data Book*, 6th ed. (Park Ridge, N.J.: Noyes Data Corp., 1982), showed for 1974-1984 an increase of energy intensity per passenger-mile by 45 percent for transit buses (largely reflecting reduced ridership), 32 percent for intercity buses, and a 4.5 percent intensity decline for school buses.

63. Personal communication, 6 June 1987, by Jaime Lerner, director, Rio de Janeiro Plan for the Year 2000 (Rua São Bento, 8. 6.° andar, CEP 20.090 Rio de Janeiro. RJ, Brasil). Lerner developed unsubsidized, U.S. 10¢/ride commuter bus systems in Rio and Curiciba, some with one-minute intervals. His on-street "boarding pods" and special door designs nearly trebled density– to a staggering 12-18,000 passengers per hour per corridor.

64. This assumes that from 1988 onward, improved mass transit holds average number of cars per household constant, and average mileage driven per car year constant at 10,000 (1 percent above the 1986 level). The saving would of course be larger in scenarios with less-efficient cars, since little fuel is saved by displacing a 60-mpg car. Still further savings, of course, are available from home occupation, mixed zoning, living nearer to where one wants to be, telecommunications, and other substitutes for physical mobility.

65. M. C, Holcomb et al., *Transportation Energy Data Book: Edition 9*, ORNL-6325, Oak Ridge National Laboratory, April 1987. During this five-year period, the use of "aerodynamic features," "variable fan drives," and "fuel economy engines" all more than doubled too, although their 1982 shares were only 83 percent, 27.5 percent, and 30.0 percent respectively.

66. A. and H, Lovins, F. Krause, and W. Bach, *Least-Cost Energy: Solving the* CO_2 *Problem* (Andover, Mass.: Brick House, 1982); G. Samuels, *Transportation Energy Requirements to the Year 2010*, ORNL-5745, 1981. Essentially identical technologies apply to buses.

67. SERI, *A New Prosperity: Building a Sustainable Energy Future* (Andover, Mass.: Brick House, 1981). This remains the most careful, complete, and knowledgeable federal efficiency analysis to date but was initially suppressed by the incoming Reagan administration, then published as a congressional committee print and by the private publisher Brick House. It was apparently placed on the administration's *Index Librorum Prohibitorum*, to be officially ignored and certainly not followed.

68. Evidence: During model years 1981-1987, the average efficiency of new cars (light trucks) rose 2.5 (2.1) mpg for domestic models seeking to avoid CAFE penalties and gas-guzzler taxes, but *fell* 0.5 (2.1) mpg for imports, which, though

selling to the same market, were almost all efficient enough to be untouched by the standards.

69. Compared with an assumed *retail* synfuel-product price of ~$70/bbl (1981 $), equivalent to $1.67/gal. This seems realistic to low in view of actual performance: Those synfuel plants that work at all seem to be able to survive only with fixed-price purchase contracts and with upstream subsidies on the order of $30-40/bbl. In late 1981, when we made the synfuels/scrappage comparison in many public forums, the estimated 1981-$ plant-gate price of synfuels was estimated by such vendors as Exxon at ~$45/bbl, but by early 1982, their estimates had soared to >$100/bbl. These costs do not include the refining/marketing/distribution markup (normally ~$12/bbl), nor kerogen's ~$5/bbl refining premium.

70. Up to some rather high ceiling or subject to a sliding scale, as marginal savings diminish at high mpg.

71. We also approached the United Auto Workers, who in principle have long supported accelerated scrappage, but apparently the union's staff has not filled the analytic void either.

72. Energy and Environmental Analysis, Inc. (Arlington, Va.), "Energy Impacts of Accelerated Retirement of Less Efficient Passenger Cars," 17 October 1980 contract to USDOE Office of Policy Evaluation under contract #DE-AC01-79PE-70032.

73. Of course, it can use refinement, e.g., to take account of people's tendency to drive new cars more and old cars less,

74. L. Schipper and A. J. Lichtenberg, "Efficient Energy Use and Well-Being: The Swedish Example," *Science* 194:1001-13 at 1005 (1976).

75. And correspondingly in other sectors: E.g. financing, for an undercapitalized airline, the re-engining of a low-bypass-engined 737 fleet on a shared-savings basis.

76. Yielding (ca. 1980) >4 MMB/D from cars and ~1.5 MMB/D more from light trucks, assuming an end-point fleet average of ~60 mpg. Efficiency gains since then have already captured ~1 MMB/D of that potential, but also permitted more ambitious end-point efficiencies at far lower marginal costs than were expected just a few years ago.

77. In addition, utilities in some regions, especially on the Gulf Coast, burn substantial amounts of natural gas to make electricity, especially to meet the peak loads arising from buildings' space-conditioning needs. The 1986 oil and gas use by U.S. electric utilities, prorated by the residential and commercial sectors' share of annual electric sales (a conservative procedure, since it neglects peaking requirements and peaking plants' lower heat rates), adds to the direct consumption an indirect consumption of 1.67 q of gas and 0.90 q of oil. The total use of gas and oil in buildings in 1986 was thus about 8.64 and 3.47 q respectively– a total of 12.11 q/y.

78. Many countries and some parts of the U.S. operate fleet vehicles on compressed natural gas; LPG operation is also common; methane can be shift-reacted to methanol using classical technology; and the Shell process to convert methane directly to gasoline shows promise of being able to be simplified to

one catalytic step, bringing its cost into an interesting range. By various methods, over varying scales of time and costs, therefore, conserving natural gas can considerably expand the range of oil-saving transportation options for direct vehicular-fuel substitution as well as for displacing oil from boiler fuel as a vehicular-fuel source.

79. Or one-and-four-fifth times the Gulf imports if indirect use by utilities is included.

80. For simplicity and conservatism, two additional kinds of savings– the free reduction in air-conditioning loads in the fueled buildings (through the shell improvements already paid for to save space heating) and the potential to save electric heating and cooling loads through similar improvements in all-electric buildings– are omitted here, though both can yield significant and quite cheap oil savings beyond those already discussed.

81. Renamed “Central Command” (USCENTCOMM) in 1983; see T. Sabonis-Chafee, op. cit. supra.

82. For illustration, Raventhal’s authoritative estimate of the FY1985 cost of Gulf forces, which are only a small portion of those allocated to Central Command, is $47 billion per year (ibid.) or a fifth of the entire nonstrategic force budget for FY1985. A more reasonable estimate of Central Command’s budget, with overheads allocated, might be about a quarter of nonnuclear forces, or about $59 billion in FY1985. Using the lower figure, and assuming LBL’s generously high average 1986-$ cost of $10/bbl for saved energy (space heating only, 1979 technologies) and a 20-year nominal measure lifetime, $47 billion would buy ~0.64 MMB/D of savings. Since the $10/bbl average cost corresponds to a larger saving than necessary–1.4 MMB/D–to displace Gulf imports, we should actually use LBL’s cost for saving only the first ~0.6 MMB/D of fuel (space heating only, 1979 technologies). That cost, $4.75/bbl, implies that $47 billion would buy not ~0.64 but ~1.36 MMB/D of savings. In contrast, Gulf imports during 1984-1986 averaged 0.57 MMB/D– less than half the savings available for one year’s Gulf-force cost.

83. Full R-11 wrap, bottom board (rigid insulation under the tank), anticonvection loops or valves (or ~15’ pipe insulation near the heater), 120°F setback, 1.5-gpm showerheads, warm-wash/cool-rinse laundry, and faucet aerators with fingertip controls. Such retrofits, if well designed, provide service equivalent or superior to original performance. Additional savings are cheaply available from stack dampers and from electric (pilotless) ignition.

84. Alpen, Inc., of Boulder, Colorado, has commercially provided R-10 glazings and can provide ~R-12 on request. (Windows in that range use two heat mirror films, an optional low-emissivity coating on one of the panes of glass, and an advanced gas fill–either krypton or krypton/CO_2.) Rocky Mountain Institute’s headquarters, in an 8700-F° -d/y climate with temperatures down to -47°F, is heated by the passive gain from older Alpen glazings rated at R-5.4 or, in a few cases, at ~R-6.7 or R-9.1.

85. Comprising 1.09 q for asphalt and road oil, 0.29 q as lubricant, 0.73 q as petrochemical feedstock, 0.82 q in the form of LPG as feedstock, 0.13 q as petroleum coke, the same as special naphtha (another feedstock), and 0.14 q

as wax and other miscellaneous products: EIA, *Annual Energy Review 1986*, p. 15.

86. And better understanding of asphalt, Although the United States spends more than a billion dollars a year on asphalt, so little is known of its composition and behavior that the reasons for the failure of certain batches, and acceptance testing techniques to avoid such failures, are still unknown, Such appalling ignorance of the basic properties of a basic economic material, accounting (with road oil) for 3.4 percent of total U.S. oil consumption, would surely not be tolerated in any area less institutionally backward than infrastructural technology.

87. The Gas Research Institute (Paul Holtberg, personal communication, 30 December 1987) estimated that as of 1985, all of the boiler fuel and ~40 percent of the process heaters can switch from residual oil to natural gas with a couple of years' lead time. (Short-term gas-to-resid-switchable capacity totaled ~1.5 q/y; total resid boiler fuel, half that.) It might be objected that the 0.75 q of residual oil used as boiler fuel cannot be displaced because it has no other use; but it can be cracked to lighter products, and over the long run, refinery modernization will greatly reduce its output. As one oil-major CEO remarked, "Why should we make it resid? It's like coal, and we already have more coal than we can sell." Curiously, the same people who argue that resid cannot be displaced in industry often assert that building more coal-fired and nuclear power plants can displace the oil still burned by electric utilities, even though 94 percent of that oil (as of 1986) is resid.

88. A modest fraction of those technologies involve substitution of electricity for fuel– for example, in ultraviolet or microwave paint drying and curing– but those additional uses of electricity seem likely to be far smaller than industrial electric *savings* through adjustable-speed motor drives and a host of other electricity-specific efficiency improvements. We estimate that ~13 classes of efficiency improvements to existing industrial drive systems can save roughly half of their input electricity, at average costs ~0.3-0.5¢/kwh.

89. Corresponding to a 3 percent increase in industrial primary energy use with a 48 percent increase in industrial value added.

90. The actual pattern was a 12.9 percent fall in industrial primary energy use with a 25.1 percent rise in real industrial output–i.e., a 30.4 percent decrease in energy intensity or a 43.6 percent increase in energy productivity,

91. Schipper and Lichtenberg (op. cit. supra) showed that in the mid-1970s it was about a third more energy efficient than U.S. industry, despite its greater share of the most energy-intensive products. Its efficiency has since improved by probably as much in percentage terms as has that of U.S. industry.

92. T. B. Johansson et al., *I Stället för Kärnkraft; Energi Ar* 2000, DsI 1983:18 (Stockholm, Industridepartementet), summarized in *Science* 219:355-361 (1983).

93. In correspondence currently in press at the *Atlantic*, Charles Ebinger and Mark Mills, *Atlantic*, June 1988, p. 10, claimed a $14 billion-a-year oil saving, Although this figure appears to be exaggerated, even taken at face value it is hardly a good buy, since the total cost of the electric capacity built to achieve that displacement exceeds $300 billion, not even counting its operating costs– which, for a typical (trouble-prone) U.S. nuclear plant exceed those of an oil

plant, based on exhaustive empirical data from Komanoff Energy Associates in New York.

94. Of course, this sensitivity would vary by region, and it reflects only first-order sensitivity, not counting possible cross-effects on the prices of other fuels or of capital. Data used in this paragraph's calculations are from *EIA's Monthly Energy Review*, March 1987, and Edison Electric Institute's (EEI's) *1986 Statistical Yearbook* (Washington, D.C.).

95. EEI construction expenditures (excluding the allowance for funds used during construction–AFUDC) for investor-owned utilities (IOUs), divided by 0.8 (IOUs' sales share) as a rough surrogate for including corresponding investments by public utilities.

96. As of FY1984. H. R. Heede and A. B, Lovins, "Hiding the True Cost of Energy Sources, *Wall Street Journal*, 17 September 1985, p. 28. Heede found that in FY1984, electrical technologies received about $30 billion (b) in direct Federal subsidies–65 percent of the >$46b/y total– even though they supplied only 13 percent of the delivered energy. Electricity, per Btu supplied, was about 11 times as heavily subsidized as were directly used fossil fuels. A dollar of subsidy to nuclear power (which got nearly $16b in subsidies–about equal to the annual retail revenues of all nuclear plants then operating) yielded about 1/80 as much energy as a dollar of subsidy to efficiency and to nonhydro renewables. It is of course these two latter classes of technologies that had their subsidies virtually abolished and nuclear power that had its subsidies largely maintained or increased.

97. Specifically, the average cost is certainly below 1¢/kwh and probably nearer .5¢/kwh (1986 $ @ 5 percent/y real discount rate). The latter cost is equivalent in its heat content– not in terms of the price of oil that would have to be burned to make the same amount of electricity– to electricity at ~$8.6/ bbl., However, the average cost of saving half of the present total electrical use is approximately zero–because the first ~120 gw of savings (in lighting and its associated net heating, ventilation, and air conditioning [HVAC] energy) has a strongly negative cost, due to maintenance savings that more than pay for the measures themselves. That negative cost counterbalances small positive costs for a roughly equal increment of nonlighting measures. All these opportunities, and practical ways to implement them with high saturation, speed, and confidence, are exhaustively documented by Rocky Mountain Institute's COMPETITEK℠ quarterly update service. A semitechnical summary of salient options is in A. B. Lovins's August 1987 testimony to and for the District of Columbia Public Service Commission (RMI Publication #87-6), which ordered a major efficiency program begun in spring 1988. A technical analysis of how to save ~75-80 percent of the electricity used in existing Austin buildings, at average costs <0.9¢/kwh, is *Advanced Electricity-Saving Technologies and the South Texas Project*, 1986 (RMI Publication #87-7).

98. Accounting for all avoidable operating costs, however–including all O & M (not just its short term variable component) and net capital additions– reveals that the typical U S. nuclear plant has levelized operating costs, all avoidable be shutdown, in the vicinity of 5¢/kwh. That is generally more than for coal-fired and often more than even for oil- or gas-fired plants, so in principle,

many nuclear plants, on strict economic-dispatch grounds, might be backed out even before many oil plants.

99. At first it might appear that for operational reasons, much of this small- and intermediate-load -factor capacity would in fact continue to operate, since large solid-fueled plants often exhibit poor load following and slow ramp rates. In practice, however, electric end-use efficiency and load management, along with better integration of hydropower and cogeneration resources, can largely if not wholly obviate this concern.

100. North American Electric Reliability Council (Princeton, N.J.), *1987 Electricity Supply & Demand*, p. 25.

101. This relies on the technically conservative SERI analysis. Watson's extended light-vehicle CAFE standards, reaching only 48 mpg for new cars and 33 for new light trucks by 2000, would yield a net saving (subtracting DOE's "market"-case projection) of 1.8 q/y. Far larger light-vehicle savings could be achieved by 2000 through any combination of higher efficiency levels and (more importantly) accelerated scrappage. The 1:88:1 crude:gasoline ratio is assumed here to be 1:1.

102. Applying SERI's projected 58 percent fuel savings in all buildings to 1986 oil use in buildings yields 1.08 q/y in oil savings, but in practice there would probably be more incentive to save oil than gas.

103. *Energy Security*, March 1987, p. 94.

104. This could be achieved just by LBL's space-heating savings in fueled buildings (costing an average of $20/bbl with 1979 technologies), to say nothing of savings in water heating and in all-electric buildings.

105. Assuming the ANL-85N2 stock forecast (134.8 million cars and 54.5 million personal light trucks) in 2000, 1,543 and 303 billion vehicle-miles per year respectively, and base-case efficiencies of 27 and 15 mpg respectively.

106. For an introduction, see our summaries in *Brittle Power: Energy Strategy for National Security* (Andover, Mass.: Brick House, 1981), pp. 358-363; in *Energy Unbound: A Fable for America's Future* (with Seth Zuckerman) (San Francisco: Sierra Club/Random House, 1986), pp. 124ff.; and with Marty Bender in W. Jackson et al., ed., *Meeting the Expectations of the Land* (San Francisco: North Point Press, 1984), pp. 68-86.

107. A. B. and L. H. Lovins, "The Fragility of Domestic Energy," *Atlantic*, November 1983, at p. 126.

108. Cost estimates at the time ranged up to at least tenfold lower than this. More recent estimates suggested that the average costs of such efficiency gains (as opposed to the marginal cost of the last increment of savings) probably fall into the range $0-10/bbl– more consonant with the costs of eliminating most of the heat-flows through building shells.

109. EM-4815-SR, 1986.

110. *In Least-Cost Energy* (op. cit. supra), for example, we showed how full use of 1980 efficiency-and-renewables technologies, cost effective at 1980 prices, could support a world of eight billion people with five times today's total economic activity (a tenfold increase in developing countries), yet eliminate dependence on Middle Eastern oil and on most other fuel resources. Goldemberg et al., op. cit infra, have convincingly extended this work.

111. Extensive details and some 1,200 references can be found in our Pentagon analysis *Brittle Power*, op. cit. supra, summarized in *Atlantic*, November 1983, pp. 118-126.

112. See A. B. Lovins, *Wall Street Journal*, 1 May 1987, op. cit. supra; “Comments on the Draft *Arctic National Wildlife Refuge, Alaska, Coastal Plain Resource Assessment*,” RMI Publication #87-2; and response to AIP Critique #020, RMI Publication #88-5.

113. *Least-Cost Energy*, op. cit. supra, summarized in *Climatic Change* 4:217-220 (1982).

114. D. J. Rose et al., *Technology Review*, May/June 1984, pp. 49-58; J. Goldemberg et al., *Energy for a Sustainable World* (Washington, D.C.: World Resources Institute, 1987). RMI researchers W. N. Keepin and G. Kats will shortly publish an analysis showing that nuclear power, contrary to widely held assumptions, cannot in principle be of much help with the CO_2 problem and indeed makes it worse by diverting investment from cheaper, faster efficiency improvements.

115. H. Geller et al., *Acid Rain and Electricity Conservation* (Washington, D.C.: American Council for an Energy-Efficient Economy, 1987).

116. In *Energy/War: Breaking the Nuclear Link* (Friends of the Earth, 1980) summarized (with Leonard Rose) in *Foreign Affairs* 58(5):1137-77 (Summer 1980); with Patrick O’Heffernan (senior author) in The *First Nuclear World War* (New York: Norton, 1983); and in numerous technical papers cited in those works.

117. A. B. Lovins, *Development Forum* (Geneva: United Nations, September 1986), p. 4.