Make Fuel Efficiency Our Gulf Strategy[1]

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[Shown in RMI's style, differing slightly from The Times'*]*

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Are we putting our kids in tanks because we didn't put them in efficient cars? Yes: we wouldn't have needed any oil from the Persian Gulf after 1985 if we'd simply kept on saving oil at the rate we did from 1977 through 1985.[2]

Even now, we could still roll back the oil dependence that perpetually holds our foreign policy hostage and distorts other U.S. priorities in the Middle East. Just by aiming at greater efficiency, we could eliminate all Gulf imports by using only an eighth less oil.[3]

A great place to start would be personal vehicles. Improving America's 19-mile-per-gallon household vehicle fleet by 3 miles per gallon could replace U.S. imports of oil from Iraq and Kuwait.[4] Another 9 miles per gallon would end the need for any oil from the Persian Gulf[5] and, according to the Department of Energy, would cut the cost of driving to well below pre-crisis levels without sacrificing performance.[6]

The Reagan Administration doubled 1985 oil imports from the Gulf when it rolled back efficiency standards.[7] Today's new cars average 29 miles per gallon; the fleet, only 20. Yet 10 manufacturers have built and tested attractive, low-pollution prototype cars that get 67 to 138 miles per gallon.[8] Better design and stronger materials make some of these safer than today's cars, as well as more nimble and peppy.[9]

And efficiency needn't mean smallness: only 4 percent of past car-efficien0cy gains came from downsizing.[10] Some of the prototype cars comfortably hold four or five passengers[11], and two of them are said to cost nothing extra to build.[12]

Many other oil savings can help. Boeing's new 777 jet will use about half the fuel per seat of a 727.[13] Technical refinements can save most of the fuel used by heavy trucks, buses, ships, and industry.[14] Insulation, draft proofing, and simple hot-water savings can displace most of the oil used in buildings.[15] Superwindows that retain heat in winter and reject it in summer could save each year up to twice as much fuel as we get from Alaska.[16]

In all, we know how to run the present U.S. economy on one-fifth the oil we are now using, and the cost of saving each barrel would be less than $5[17]. Even achieving just 15% of that potential oil savings would displace all the oil we've been importing from the Gulf.[18] Doing that requires only a small additional step: since 1973, we've reduced our oil use per dollar of GNP 4 1/2 times as much as we need to today in order to eliminate all Gulf imports.[19]

How can we promote fuel efficiency? Higher gasoline taxes are a weak incentive to buy an efficient car, because gasoline costs four times less than the non-fuel costs of owning and running a car. And since the often higher purchase price of efficient cars about cancels out the lower gasoline bills, the total cost per mile for 20- and 60-mile-per-gallon cars is about the same.[20]

But the 40-mile-per-gallon difference, for cars and light trucks, represents more than twice America's imports from the Gulf.[21] If the security and environmental costs of inefficient cars had to be paid up front, buyers would choose more wisely. The best way is "feebates": when you register a new car, you pay a fee or get a rebate, depending on its efficiency. The fees pay for the rebates.

Rebates for efficient cars should be based on the difference in efficiency between your new car and the old one—which you'd scrap, thus getting the most inefficient, dirtiest cars off the road first.[22] That's good for Detroit, for the poor, for the environment, and for displacing Gulf oil sooner.

The California Legislature recently approved car feebates by a margin of 7 to 1.[23] Connecticut, Iowa, and Massachusetts are weighing them.[24] Feebates are also being considered for new buildings in California, Iowa, Massachusetts, and the four Northwestern states, and could be applied to trucks, aircraft, appliances, and other energy-consuming goods. Unlike miles-per-gallon standards[25], feebates reward maximum performance and encourage business to bring superefficient models to market.

Energy efficiency is also the key to the decades-long transition to nondepleting, uninterruptible energy sources. Government studies confirm that sun, wind, water, geothermal heat, and farm and forestry wastes can cost-effectively provide, within 40 years, half as much energy as America uses today.[26] Efficiency would raise that share[27] and buy the time needed for graceful conversion.

The military alternative to energy efficiency isn't cheap. Gulf jitters have added over $40 billion a year to U.S. oil imports.[28] Counting military costs, Gulf oil now costs us over $100 a barrel.[29] The more than $20 billion net cost of the U.S. forces in the Gulf just from August through December 1990[30], if spent instead on efficient use of oil, could displace all oil now imported from the Gulf.[31] It could also create jobs and wealth, improve America's trade balance, stretch domestic reserves, clean urban air, cut acid rain and global warming, and help the poor at home and abroad.

In 1989, the Pentagon used about 38 percent as much oil as the U.S. imported from Saudi Arabia[32], and estimated that its consumption could readily double or triple in a war[33]. An M-1 tank gets 0.56 miles per gallon.[34] An oil-fired aircraft carrier gets 17 feet per gallon.[35] And no good outcome—in dollars, oil, or blood—is in sight.

But from inside an efficient car, the Gulf looks very different. From inside enough of them, its oil becomes irrelevant.[36] National security, peacetime jobs in a competitive economy, and the environment demand immediate mobilization—not of tanks but of efficient cars, not of B-52s but of 777s, and not of naval guns but of caulk guns.

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[1] This annotated edition includes summaries of the basis for the numbers presented, and some further amplification. Unless otherwise noted, data are from the U.S. Energy Information Administration's *Monthly Energy Review / June 1990*, DOE/EIA-0024(90/06) (hereinafter *MER:*page) or from EIA's *Annual Energy Review 1989*, DOE/EIA-0384(89) (hereinafter *AER*:page).

[2] We choose the period 1977-85 because it is when the Corporate Average Fuel Economy (CAFE) standards for cars and light trucks, passed by Congress in 1975, were in force in their original statutory form. (The standards came into effect with model-year-1978 vehicles, and were rolled back for model-year-1986-through-1988 vehicles.)

According to *MER*:15,20, the U.S. in 1977 consumed 37.122 quadrillion BTU (q) of petroleum (including natural gas plant liquids and lease condensate) to fuel a $2.959-trillion (1982) GNP—a ratio of 12.545 thousand BTU/1982 $. For 1985, the corresponding figures were 30.922 q, $3.619 trillion, and 8.544 kBTU/1982 $. The compound rate of decrease thus averaged (In [8.544/12.545])/8 = 4.80%/y.

We present first an example for 1989: had this rate of improvement in oil productivity been sustained during 1986-89, the oil intensity in 1989 would have been $8.544(1 - 0.048)^4 = 7.017$ kBTU/1982 $, which times the 1989 GNP of $4.118 trillion (1982 $) would have yielded petroleum consumption of 28.90 q. Actual 1989 petroleum consumption, however, was 34.211 q. The difference, 5.31 q/y, was equivalent at the 1989 average petroleum-import heat value of 5.837 million BTU per barrel (MBTU/bbl) (*MER*:130) to 2.493 Mbbl/d. Gross imports from the Gulf in 1989 (*MER*:50—Arab OPEC plus Iran minus Algeria and Libya—averaged 2.093 Mbbl/d. (Net imports from Arab OPEC [*MER*:21], *i.e.*, imports less exports, were only 2 kbbl/d less, an insignificant correction.) Thus a 2.493-Mbbl/d reduction in U.S. oil requirements probably would have, and certainly could have, extinguished 2.093-Mbbl/d imports from the Gulf.

Interestingly, the same is true *throughout* the years 1986-90 inclusive: in 1986, 1987, 1988, and 1990 (annualized from first-half data) respectively, continuation of the 4.8%/y improvement in oil productivity would have yielded oil savings (*vs.* actual consumption) of 0.922, 1.402, 2.167, and 2.556 Mbbl/d—consistently greater than the respective Gulf imports of 0.910, 1.077, 1.540, and 2.093 Mbbl/d. Thus in *no* year after 1985 would the U.S. have needed Gulf oil, but for the loss of oil-saving momentum in 1986.

In 1985, imports from the Gulf had nearly been eliminated, falling to only 0.312 Mbbl/d—an 87% reduction from its 1977 peak of 2.438 Mbbl/d. (Note how quickly this near-extinction occurred.) That import level was so low that it would have been eliminated entirely by just another 1-mpg gain in the efficiency of the U.S. car fleet. But instead of continuing down to zero in 1986 and thereafter, they nearly tripled to 0.910 Mbbl/d in 1986, only because 1986 U.S. oil intensity, rather than continuing to decline at an average rate of 4.8%/y, *rose* by 1.4% (from 8.544 to 8.659 kBTU/1982 $). The dominant reason for this rise appears to have been the sudden, and largely deliberate, 1986 collapse of previously steady improvements in light-vehicle efficiency (*infra*).

[3] Net oil imports from the Gulf in the first half of 1990 (*MER*:50) averaged 2.060 Mbbl/d, or 12.1% of the 16.949 Mbbl/d of total petroleum products supplied (*MER*:21).

[4] The latest published data on the household vehicle fleet (personally owned cars and light trucks, plus a trivial amount of consumption for motorcycles, recreational vehicles, etc.) are for calendar 1988 (*AER*:51; see also *Household Vehicles Energy Consumption 1988*, DOE/EIA-0464(88)). In 1988, that fleet had 147.5 million vehicles, traveled 1.511 billion miles, consumed 82.4 billion gallons of motor fuel (81.0 of it gasoline), and averaged 18.3 miles per gallon—slightly lower than the 20.0 mpg for passenger cars (*AER*:53) because of the ~5mpg lower efficiency of light trucks. (It appears likely that the 1989 and 1990 efficiencies are slightly better—1989 total gasoline consumption divided by 1989 registered cars [*AER*:55] was 1.4% below the 1988 figure—but the mpg data corrected for miles driven aren't yet available.) Since passenger-car efficiency improved by 0.75 mpg during 1987-88, but that improvement probably slowed somewhat with the intensive marketing of muscle cars in 1988-90 and was also diluted by ~4-mpg-worse light trucks and vans, we assume that the household vehicle fleet currently averages ~19 mpg.

We also slightly adjust the last published (1988) average annual miles driven per household vehicle, 10,244, by assuming that it grew half as fast during 1988-90 as it did for passenger cars during 1986-88 (*MER*:23)—the phase of the steady 1980-88 mileage growth most representative of fuel prices through mid-1990. This implies mileage growth of 1.312%/vehicle-y or a ~1990 average distance of 10,515 miles/vehicle-y. (This growth rate virtually equals the 1.27%/y compound rate in passenger-car miles/vehicle-y observed during 1980-88: *MER*:23.)

We further assume that the household vehicle fleet grew at the same rate during 1988-90 as during 1988-89, implying 4.4% growth from 147.5 million vehicles to 154.0 million.

On this basis, had the ~1990 household vehicle fleet enjoyed an average efficiency of 22 instead of 19 mpg, its ~1990 fuel consumption would have been 75.5 gal/vehicle-y less, or 1.797 bbl/vehicle-y, or 0.758 Mbbl/d. This essentially equals early-1990 gross imports from Iraq and Kuwait, which according to press reports were ~0.788 Mbbl/d (~4% more) around April 1990. As a major conservatism, however, barrels of motor fuel have been assumed equivalent to barrels of the import mix of crude oil plus refined products: this takes no credit for refinery losses, nor for the impossibility of getting a barrel of light products out of a barrel of crude. In fact, in the first two thirds of 1990, to produce a barrel of motor gasoline (which was 98.3% of the fuel consumed by the 1988 household vehicle fleet: *AER*:51), U.S. refiners needed 1.96 barrels of crude oil (*MER*:49.53). We shall revisit this important point in note 7 *infra*.

[5] The same calculation for a shift from 19 to 19+3+9 = 31 mpg yields a saving of 224.8 gal/vehicle-y or 5.353 bbl/vehicle-y or 2.259 Mbbl/d. This exceeds first-half-1990 Gulf gross imports (*MER*:50) of 2.060 Mbbl/d. (Recalculating, conservatively, with the actual 1988 fleet size and miles driven would yield 2.00 Mbbl/d.)

[6] Carmen Difiglio, K.G. Duleep, & David L. Greene, "Cost Effectiveness of Future Fuel Economy Improvements," USDOE, August 1988 (published in *The Energy Journal* in late 1989) describes 15 available, demonstrated improvements that can be incorporated into normal car production and that "would not reduce performance, ride, or capacity over 1987 levels." (These plus two more such measures are summarized by Marc Ledbetter & Marc Ross in "A Supply Curve of Conserved Energy for Automobiles," *Procs. 25th Intersociety Energy Conversion Engineering Conf.*, Reno, 12-17 August 1990, Am. Inst. Chem. Engrs., NY.)

These 15 measures, if fully used in an average 1987 new car sold (domestic or imported), would collectively improve its actual on-road efficiency from 28.3 to 39.4 mpg. (More recently, the DOE authors have adjusted this downward to ~38 mpg.) This improvement is considerably larger than that required (see note 5) to eliminate Gulf imports, since similar technologies are also applicable, to ~70% the extent and at about half the unit cost, to light trucks, as described more fully by Ledbetter & Ross (1989), Attachment B to Icf, *Preliminary Technology Cost Estimates of Measures Available to Reduce U.S. Greenhouse Gas Emissions by 2010*, August 1990 draft report to USEPA.

Ledbetter & Ross (Reno paper, *op. cit.*) have compiled Difigilio *et al*'s costs for the 15 efficiency-improving measures, plus two more which raise the total efficiency gain by a further ~4 1/2mpg. Even making generous allowance for the difference between rated and actual on-road performance, the resulting efficiency, using the correct multiplicative methodology, would be ~33.7 mpg—more than enough to satisfy the no-Gulf-imports criterion. The total marginal cost of that package of measures, ~69% more efficient than the present U.S. car fleet, is equivalent to buying gasoline at ~53¢gal (1987 $). Since this is about half the real price of gasoline before the current Gulf crisis, total driving costs would go down if such efficiency measures were adopted. (As a reality check, at least seven mass-produced cars with actual performance over 42 mpg [55 EPA-rated mpg] are already on the U.S. market, and some are selling very well.)

Difiglio *et al*'s analysis of their 15 measures is highly conservative. For example, they assume a drag coefficient of 0.3, even though the Ford Sable and several other models already do better, Renault's Vesta 2 prototype achieves 0.186, the experimental Ford Probe V gets 0.137, and aerodynamicist Paul MacCready says it's straightforward to get 0.12 with excellent esthetics. A curb weight of 2,490 lb, only 10% below the recent U.S. average, is also assumed, even though that's ~2.4 times as heavy as some 4- to 5-passenger prototypes (*infra*), and ~500 lb heavier than can be readily achieved, thereby reaching ~50 mpg, by materials substitutions *alone*: M.C. Flemings *et al*, *Materials Substitution and Development for the Light Weight, Energy Efficient Automobile*, report to U.S. Congress's Office of Technology Assessment, 8 February 1980.

[7] The standards became law in 1975 because Congress appreciated the need to correct the market failure referred to four paragraphs below. Buyers could choose any car they liked and, if it weighted under 6,000 pounds and got less than 22.5 mpg, pay a tax (up to $3,850 for a 10-mpg 1987 Rolls-Royce). Manufacturers had to meet a fleet-average efficiency standard rising from 18 mpg for model year 1978 to 27.5 mpg for model years 1985-88. In practice, however, sales of 1986 and 1987 cars beat the 27.5-mpg standard only because Americans bought record numbers of imported cars averaging over 30 mpg. Domestic cars' 26.6 and 26.7 mpg flunked, as they did throughout model years (MY) 1983-87. Although Chrysler met the standards in every year, Ford and General Motors flunked them for at least six years running, starting with model year 1983.

Through an administrative proceeding (for which only the automakers, apparently, have standing to obtain judicial review), the Reagan Administration rolled back the 1986-88 standards from 27.5 to 26.0, 26.0, and 26.5 mpg. These were chosen as levels that Ford and GM could readily beat, so that they could *retroactively* offset with credits for "overcompliance" more than $1 billion (the exact figure is an official secret) in statutory fines for their willful noncompliance in 1985. (Their earlier noncompliance had been offset by credits for "overcompliance" in the early years of CAFE, when fleets improved faster than the standards rose. CAFE didn't originally allow such carryforward credits, but was so amended in 1979 at the behest of the automakers. But in MY1985, they ran out of credits, so their noncompliance incurred an automatic fine calculated by its degree and the number of noncomplying cars sold. When even the 1986-88 rollback wasn't enough to bail out GM, the Reagan Administration even considered a retroactive rollback of the 1985 standard!)

This 1986-88 rollback, undertaken entirely for Ford and GM's benefit, competitively penalized Chrysler's compliance; told GM and Ford they could defy Congress with impunity, and emboldened them to intensify their ferocious marketing (via rebates and other incentives) of their least efficient models. Their sales crusade was aided by the inability of two-thirds of new-car buyers to get a copy of the government's "Gas Mileage Guide," whose print run was reduced 70%—the well-known Telepathic Theory of Market Information.

The result of these initiatives was not, as the Department of Transportation's press release trumpeted in announcing the 1988 rollback, "to enhance U.S. global competitiveness and protect jobs"; rather, it was to cut the 1985-86 gain in U.S. car-fleet efficiency by 81%, to a 10-year low of only 0.07 mpg—only 11% of the 1979-85 average of 0.615 mpg per year (*MER*:23). Concurrent rollbacks in light-truck efficiency standards cut their fleet improvement by 67%. This 1986 stall in previously steady improvement in light-vehicle efficiency *doubled U.S. imports from the Persian Gulf*, and was hence responsible for half the tripling of Gulf imports during 1985-86.

Calculation: in 1986, the average car in the U.S. fleet was driven 9,608 miles (*MER*:23). Had it achieved the average 1979 through 1985 improvement of 0.615 mpg/y (*id.*), it would have had an efficiency of 18.82 mpg rather than the actual 18.27 (*id.*), so it would have used 15.23 gal/y less gasoline. Multiplying by the 1986 fleet of 117 million cars (ORNL data), that's 115.92 kbbl (@ 42 gal/bbl) of gasoline per day. On-road mpg in 1986 was ~15% worse than EPA-rated mpg, multiplying this by 1/1.15 = 1.18 (DOE methodology) to 133.31 kbbl/d. In 1986 it took 1.88 bbl of crude oil to make 1 bbl of gasoline (*MER*:49,53), so since imports are driven by light-product demand, the increase in crude-oil imports was 133.31 x 1.88 = 250.62 kbbl/d.

For light trucks, the database is poorer, but a good approximation can be obtained from 1988 Oak Ridge National Laboratory data (Phil Patterson, personal communications, and *Oak Ridge Transportation Energy Data Book*). The MY1986-87 (or roughly calendar-year 1985-86) new fleet gain was 0.20 mpg, compared with the MY1979-86 average of 0.60 mpg/y. The average light truck in 1985 (1986 data are uncertain) was driven 11,016 mi, so the MY1987 shortfall of 0.40 mpg used an extra 9.9 gal/truck-y, times ~38 million light trucks in use in 1986, times 1.18, times 1.88, equals 54.4 kbbl/d of crude oil. (Reliable data on the whole fleet of old-plus-new light trucks have been unavailable since 1982 [12.4 mpg]; dilution by old trucks is somewhat offset by higher first-year driving in new ones. The MY1986 rollback for light trucks was generally from 21.0 to 19.5 mpg.)

The total extra crude oil thus required in 1986 by the collapse of the 1979-85 rate of light-vehicle efficiency improvement was thus ~250.6 + ~54.4 = ~305 kbbl/d, essentially identical to 1985 net Gulf imports of 306 kbbl/d (*MER*:21,50). This extra crude-oil requirement is also slightly more than the 30-year average rate (295 kbbl/d) at which the Interior Department hoped to get oil from beneath the Arctic National Wildlife Refuge.

[8] Ten examples from eight companies were described in Debbie Bleviss's *The New Oil Crisis and Fuel Economy Technologies* (Quorum Books, Westport CT, 1988) and "Saving Fuel," *Technology Review*, pp. 47-54, November/December 1988, and by J. Goldemberg *et al*., *Energy for a Sustainable World*, Wiley Eastern (New Delhi), 1988. The remainder, from Audi, Citroen, GM, Fiat, Honda, Nissan, Volkswagen, and others, have been reported more recently in the trade press. The 138-mpg figure was reported in the European trade press for a Volkswagen prototype in mid-1990. Among the most interesting prototypes are the 4-5 passenger Toyota AXV (98-mpg composite rating, derived from EPA ratings of 89 mpg city and 110 highway) and the 4-passenger Renault Vesta 2, tested in 1987 at 101 city and 146 highway, or 121 composite mpg.

[9] Bleviss, *op. cit*. For example, Volvo's LCP-2000, using rather old technology, passes the DOT head-on-crash passenger-survival test at 35, not the required 30, miles per hour—a 36% increase in absorbed collision energy. Most of the prototypes also use very light, strong composite materials that bounce better, and some use energy-absorbing structural "cages" around the passengers. In general, while there is a correlation between cars' weight and their crashworthiness in collisions with other moving objects, there is not a necessary *causal* link, because design and materials are far more important than weight. This is easily demonstrated by observing that some of today's heaviest cars do poorly in crash tests, while some of the safest are very light. In addition, many superefficient cars accelerate *faster* than today's average car (Bleviss, *op. cit.*), because their light weight is more important than their smaller horsepower. This faster acceleration, shorter stopping distance, and more agile handling should also help them avoid accidents in the first place.

[10] As calculated by Phil Patterson of Oak Ridge National Laboratory for the period 1976-87 ("Periodic Transportation Energy Report #1" [16 November 1987]): *i*.e., "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 less than the actual value). Thus, if in 1987 the nation had reverted back to the 1976 new car size mix, the eleven year gain of 10.9 MPG would have been reduced by only 4 percent."

This is not true, however, for light trucks, whose efficiency jumped dramatically in the late 1970s as small imported pickup trucks entered the fleet: this truck downsizing, which was more a phenomenon of marketing to new, more urban segments than of sacrificing comfort among traditional pickup drivers, accounted for 42% of the 1976-87 improvement in light-truck efficiency (*id*.).

[11] See *e.g*. Bleviss, *op. cit*.

[12] This refers to the Volvo LCP-2000 (at a breakeven production rate of only 20,000 units a year) and, according to oral information not formally citable in literature, to a 92-mpg Peugeot. The main reason for the roughly zero marginal cost is that to achieve such cars' 1200-1400 lb curb weight requires extensive use of plastics and composites. Large, complex assemblies can then be molded as a unit and snapped together. Not having to make and assemble many small parts, and being better able to design for easier assembly, saves more money than the molding dies and the more exotic materials cost. The leftover money pays for better aerodynamics, smarter chips controls, etc., and the total net marginal cost is about zero. This negative cost of major weight reduction is consistent with consultancy data recently provided to Mark Ledbetter of ACEEE (personal communication, 8 October 1990) and with Chrysler's finding (*Automotive News*, p. 36, 5 May 1986, "Chrysler Genesis Project Studies Composite Vehicles") that a largely plastic-composite car

could cut a steel car's part count by 75% and its production cost by up to 60%. Plastic and composite parts can also improve safety and greatly reduce maintenance and repair costs, although they require careful design for recyclability. Even greater efficiency than 67-138 mpg, with even better performance, appears to be technologically possible with more systematic and fundamental design improvements (A.B. Lovins, *Least-Cost Climatic Stabilization*, 15 October 1990 Mitchell Prize paper for release 6 March 1991, p. 8).

[13] Donna Mikov and Tom Cole (Boeing Corporation), personal communications, 16 November 1990: ~94.5 seat-mile/gal, *vs*. the 727-200's 50. The 777 is also to burn 35% less fuel per seat-mile than a typical DC-10: ~185 lb/2000 mi, *vs*. 285 for a DC-10-30, 210 for a 747-400, or 205 for a 767-300ER. However, the 777 will not include the unducted fan engine developed by GE. That engine, originally developed and flight-tested for the unsold 7J7, uses ~40% less fuel per unit of thrust than the 727's JK8D-17 engines: against its nearest competitor, its saved energy (levelized at a 5%/y real discount rate) costs only 19¢/gal. (See also Lovins, *Least-Cost Climatic Stabilization*, pp. 10-11.)

[14] See sources cited in Lovins, *id*. (pp. 11-14) and A.B. & L.H. Lovins, "Drill Rigs and Battleships Are the Answer! (But What Was the Question?)" (at pp. 83-138 in R.G. Reed II & F. Fesharaki, *The Oil Market in the 1990s*, Westview, Boulder, 1989). The citations support 50-60% savings for heavy trucks (40% was prototyped in 1983) and probably in buses, ~50+% in ships, and from ~30-40% to ~90% (the latter usually including materials-policy options) in industrial process heat. Industrial efficiency opportunities continue to expand: leading European chemical firms, for example, even though they have already halved their fuel intensity since 1973, are privately reporting *additional* reductions *averaging* 70%, with two-year paybacks, from pinch technology (a method of thermodynamically optimizing process design) and better catalysts.

An option often proposed is not included in this list—saving oil used to make electricity. It was omitted for two reasons. First, oil-fired power plants represent only 5% of electric generation and 4% of oil use. Second, the cheapest way to displace them is to deploy the superefficient lights, motors, appliances, etc. that now suffice, according to RMI's exhaustive analyses, to save three-fourths of U.S. electricity, severalfold cheaper than just *running* a coal or nuclear plant, even if building it cost nothing (A. Fickett *et al.*, *Scientific American*, September 1990, pp. 64-74). (Even the utilities' think-tank, EPRI, has found a potential to save ~33-53+% of U.S. electricity in the 1990s: *id*.) Such savings could displace not only oil-fired power plants but also uncompetitive coal and nuclear plants, whose enormous costs have for so long perpetuated oil-import dependence by diverting investment away from energy efficiency. The $20-odd billion investment required (conservatively reckoned: see note 29 *infra*) to displace today's Gulf imports is roughly a tenth of the investment actually squandered in recent years on unnecessary U.S. nuclear power plants, at least 27% of which actually displaced coal.

Interestingly, DOE data clearly show that energy savings (reductions in primary consumption per real dollar of GNP) outpaced the expansions of coal-plus-nuclear output by threefold since 1973, fourfold since 1979, and sevenfold since 1985: without the 1973-86 coal-plus-nuclear expansion (but assuming no reallocation of its resources), 1986 oil imports, being nearly offset by oil savings elsewhere, would have risen by at most 5%.

It may be proposed that more nuclear plants could provide the electricity needed to displace oil in applications other than present electric generation. However, for the non-utility uses that consume 96% of U.S. oil, such as road transportation, electricity is impractical or uncompetitive. While electric cars, for example, may be suitable for some highly specialized niche markets, they cannot in principle, even with extraordinary battery breakthroughs, compete with very efficient *fueled* cars—basically because they have to carry around such a mass of batteries. (However, making the electricity onboard from fuel, using a small engine/generator or a fuel cell—the so-called "series hybrid" approach—is extremely promising.)

[15] For example, the Solar Energy Research Institute's major study *A New Prosperity* (1981), assuming 1979 technologies, found that careful retrofits could save 50% or 75% of U.S. space heat at average costs of $10/bbl and $20/bbl respectively—severalfold cheaper than buying heating oil. (See also Lovins & Lovins, "Drill Rigs...," *op. cit. supra*.) Technological progress since has cut these costs by probably half: for example, "superwindows" now on the market insulate 2–4 times as well as triple glazing but cost about the same. Similarly, RMI's 1986 Preliminary Edition of *The State of the Art: Water Heating* identified a package of eight measures that can save about two-thirds of domestic water-heating energy with paybacks of a few months.

[16] Prof. A.H. Rosenfeld (Lawrence Berkeley Laboratory) has published calculations showing that full conversion to ~R-4 windows can save half as much oil and gas (fungible for oil) as the U.S. currently gets from Alaska. However, such windows are now commercially available in the ~R-11+ range, *i.e.* with almost two-thirds lower heat flow, at scarcely higher prices. Steve Selkowitz of LBL has shown that just ~R-7 windows yield a net winter heat gain facing in any direction in any U.S. climate below the Arctic Circle, thus reducing the windows' heat loss to zero *or less*. Furthermore, Prof. Rosenfeld's calculation conservatively counts only space-heating, not -cooling, savings, but superwindows do both. Savings in south- and west-facing Sunbelt windows appear to be comparable to those in north-facing Frostbelt windows.

To illustrate the size of the savings available, *MER*:31 shows that 1989 U.S. nonindustrial buildings used 2.668 q of oil, 7.713 q of gas, and 5.851 q of electricity. (How much of that electricity was made from oil and gas? According to *MER*:37, conservatively prorating on total generation would imply the consumption of at least 2.95 q of gas and oil to make electricity for buildings. However, economic dispatch and the relatively peaky nature of most building space-conditioning loads imply a larger oil- and gas-fired share of this marginal generation. It can't be *all* oil-and-gas fired: if it were, the heat rates implied by *MER*:84,87,131 and the grid loss shown by *MER*:84,85 would imply a heat rate of 11,253 BTU of oil and gas per delivered kW-h, hence a primary consumption of 19.3 q for this purpose. That exceeds the 4.53 q of oil and gas actually consumed in 1989 to make electricity [*MER*:37]. We therefore take a range of 2.95-4.53 q of oil and gas input to make the electricity to run 1989 U.S. buildings, and consider the higher value more plausible.)

Of this total of 13.33-14.91 q of oil and gas, equivalent to and fungible for 6.3-7.0 Mbbl/d of oil (*MER*:130), DOE estimates (1983 data in *FY1987 Energy Conservation Multi-Year Plan*, July 1985, p. 41) that space heating and cooling used 93% of the oil, 73% of the gas, and 39% of the electricity—a total equivalent to 9.26-12.64 q or 4.35-5.94 Mbbl/d. The higher figure is more reasonable, as it allocates oil- and gas-fired generation entirely to space-conditioning loads (40% of which, in consequence, are still powered by other fuels). Of these space-conditioning loads, DOE ascribes 98% of the oil and gas, and 49% of the electricity, to space-heating requirements.

About a third of buildings' heat loss is through windows (Rosenfeld, personal communication, 2.XII.90, although he conservatively reduces this to a fourth for commercial buildings, which used ~38% of 1983 space-heating energy). Essentially all of that heat loss can be displaced by superwindows—*and more*, since > R-7 windows would yield a net passive-solar winter heat gain that displaces additional space-heating fuel. It's reasonable to assume that a third of the average building's space-cooling load is also due to windows. (There is an inherent conservatism in the space-cooling calculation, especially for the commercial sector: we haven't taken credit for reduced pumping and air-handling requirements to deliver coolth, and the pumps and fans save energy on a cube-law basis.) Windows' space-conditioning load thus totals ~1.5-2.0 Mbbl/d *without* counting superwindows' net passive winter gain, which could displace much, and ultimately about all, of the two-thirds of the space-heating load *not* due to windows. (RMI's headquarters, in an ~8,700°F-d/y climate with temperatures down to -47°F, is >99% passively heated by R-5.3 superwindows.) That ~1.5-2.0+ Mbbl/d is at least three-fourths of recent Alaskan output (the 30-y average of Prudhoe Bay output is ~1.5 Mbbl/d); indeed, Rosenfeld finds 1 1/2 Mbbl/d for windows' heat *loss* alone, not counting their cooling load or net-passive-gain potential. Superwindows in the ~R-7+ range would certainly save ~3-4+ Mbbl/d, or up to about two Alaskas' worth of fuel output, if one took credit for their ability to save more space heat than the original windows lost because the superwindows would be net sources of winter passive-solar heat in all climates: the two-thirds of space-heating oil and gas not ascribed to window losses, and thus available to be so saved, totals an additional 2.5 Mbbl/d. Superwindows' marginal cost is only a few $/bbl; not surprisingly, they are rapidly taking over the U.S. glazing market.

[17] The attached supply curve summarizes this finding (the actual average cost found was ~$2 1/2/bbl in 1986 $ levelized at a 5%/y real discount rate). The curve assumes full retrofit or substitution with the best demonstrated 1988 end-use technologies, documented in Lovins & Lovins, "Drill Rigs...," *op. cit. supra*. (Although that paper estimated a smaller and costlier saving through failure to take credit for the negative-cost utility-fuel savings). Shaded areas on the curve represent savings of natural gas that then displaces oil used to heat buildings or industrial processes. The costs shown above $10/bbl are quite uncertain, and generally conservative, but this has little effect on the result. The curve assumes no lifestyle changes nor intermodal transport shifts. It reflects many conservatisms: *e.g.*, omitting any light-vehicle efficiency improvements whose marginal cost exceeds zero, and translating the negative-cost lighting retrofits (which save the oil- and gas-fired electricity) directly into equivalent $/bbl without taking credit for the value of the fuel displaced. (The lighting retrofits, which more than suffice to save the oil and gas used in power stations, are documented in A.B. Lovins & R. Sardinsky, *The State of the Art: Lighting*, RMI/COMPETITEK, 348 pp., 1988.) The 1986-90 deflator is approximately cancelled by improvements in the size and cost-effectiveness of available savings owing to the concurrent technological improvements and fuller demonstration of existing capabilities, especially in industrial process-heat savings and aircraft. The overall uncertainty appears to be ~10 percentage points in total quantity and <2x in average cost.

[18] That is, 15% of an ~80% potential saving yields the 12% (of current petroleum consumption) that equals Gulf imports (note 3 *supra*).

[19] At the 1973 intensity (12.697 q petroleum/1982 $), fueling the annualized first-half-1990 GNP ($4.153 trillion in 1982 $) would have required 52.731 q of oil—19.54 q more than the actual petroleum consumption of 33.192 q (*MER*:15,20). Expressed in average-import terms (*MER*:130), that 19.54 q is equivalent to 9.165 Mbbl/d. That is 4.45 times the first-half-1990 Gulf gross imports of 2.06 Mbbl/d.

[20] The statements in this paragraph have been extensively documented by Frank von Hippel (Princeton University), the National Academy of Sciences, and others. For example, the 1987 version of von Hippel's graph showed that a typical 1987 new car costing $7,000 in 1981 $, equivalent to $9,405 in 1989 $, incurred total costs per mile (1981 $) of ~5¢ for maintenance, ~4 1/2¢ for parking, garage, and tolls, ~2¢ for insurance, nearly 1¢ for fees and taxes, and >5¢ for debt service—a total of >19¢/mi. At $1.25/gal (equivalent to -$1.75/gal today, only modestly more than the present price of premium unleaded), the total cost of driving was then ~25¢/mi at 20 mpg, failing only ~2¢/mi at 30 mpg and another ~1¢/mi at 60 mpg. Meanwhile, however, the [liberally] estimated marginal cost of the efficiency gains made the total cost of driving flat from about 40 to 90 mpg, and only ~2¢/mi lower at 20 than at 60 mpg. This slight margin (~$200/y for the average driver) would rapidly vanish or reverse if manufacturers started attaching any premium to the price of efficient models.

[21] Reccalculating the 1988 passenger-car consumption (*MER:*23) at 60 mpg instead of the actual 1988 fleet average of 19.95 mpg would reduce consumption per car (driven 10,119 miles in 1988 extrapolated to 10,386 in 1990 per note 4 supra) by 347-5 gal/car-y or (assuming no refinery loss or non-motor-fuel products) 8.274 bbl/car-y. Multiplying by the passenger cars registered in 1989 (144.4 million [*AER:*55] extrapolated to 147.6 million in 1990) yields 3.345 Mbbl/d—only 1.62x Gulf imports. Including the analogous efficiency improvements in household light trucks increases this factor to well over 2. (Interestingly, as Phil Patterson's ORNL "Periodic Transportation Energy Report #2" showed [23 December 1987], although light trucks accounted for less than a third of 1987 light-vehicle sales, they may account for nearly half of the lifetime fuel use of those vehicles sold, since they are less efficient, are driven more miles, and last longer.)

[22] Prof A.H. Rosenfeld of Lawrence Berkeley Laboratory has also devised a more elaborate system for accelerating the scrappage of inefficient cars already in the used-car market.

[23] On 30 August 1990, by votes of 31-2 in the Senate and 61-11 in the Assembly, Senate Bill 1905, sponsored by Sen. Hart of Santa Barbara, was sent to Governor Deukmejian, who vetoed it after the legislative session. But his successor, Governor-elect Wilson, has endorsed the measure (as did Wilson's opponent, Mayor Feinstein), so repassage is expected in the 1991 session. The form passed, "Drive +" (Demand-based Reduction In Vehicle Emissions Plus [fuel efficiency]), actually provided for two independent feebates—one on efficiency (measured in terms of CO_2/mile so as not to be Federally preemptable) and the other on emissions. Thus, if you bought a clean, efficient car you'd get two rebates; if you bought a dirty, inefficient car you'd pay two fees. The originally

proposed slope, $200/mpg better or worse than 28.2 mpg, was watered down to $14/mpg, but could readily be raised by later amendment once the administrative apparatus was shown to work properly. Interestingly, although Ford urged the Governor's veto, GM remained neutral—reportedly because it much prefers feebates to standards.

[24] These proposals are not all of the same form, however; in Massachusetts, for example, the 5% sales tax would swing over a 0-10% range, so the rebate would be relative to the normal tax rate, not an additional cash-back payment.

[25] Which, however, can be extremely effective: the CAFE standards and associated gas-guzzler tax were largely responsible for achieving new-car efficiencies comparable to those of Western Europe and Japan, which got to about the same place by a different kind of intervention—taxing gasoline enough to raise its price to several times the U.S. level (D.L. Greene, "CAFE or Price? An Analysis of the Effects of Federal Fuel Economy Regulations and Gasoline Prices on New Car MPG, 1978-89," ORNL/DOE, 10 May 1989 draft). Greene has further calculated that 1975-87 fleet efficiency improvements in cars and light trucks were saving some 35 billion gal/y by 1987, equivalent in net present value to $260 billion, at a cost of at most $80 billion.

[26] *I.e.*, 42 q/y in 2030 with either accelerated R&D or partial internalization of environmental costs and benefits: Solar Energy Research Institute (and four other National Laboratories), *The Potential of Renewable Energy*, Interlaboratory White Paper, SERI/TP-260-3764, March 1990.

[27] In our opinion, to 100% if much of the currently cost-effective efficiency potential were also captured by 2030.

[28] In round numbers, the Gulf crisis has raised world crude-oil prices by at least $15/bbl. Net imports from all countries in the first half of 1990 (*MER:*21) averaged 7.654 Mbbl/d. Since imports nowadays are nearly always at prevailing world prices, this implies an annual increase on the order of $42 billion.

[29] The readiness costs of Central Command forces—those whose primary mission is Gulf intervention—were ~$46 billion in FY1990 (as estimated by Prof. Earl Ravenal of the Center for Strategic and International Studies). This figure is so large because CentComm has first-priority commitments from roughly one-fourth of the U.S. active Army and Marine divisions, aircraft carriers, and fighter wings.

In addition, the marginal cost of Gulf forces' deployment at the October 1990 level of was estimated by Defense Secretary Cheney at $1 billion per month (D.R. Francis, "U.S. Treasury Reaps Windfall in Oil Crisis," *Christian Science Monitor*, 12 October 1990, p. 8) and anticipated at about the same level ($11.5 billion for FY1991) by Congress (*id.*) in the Budget Summit agreement for FY1981, starting 1 October 1990.

Part of that marginal cost is being borne by Gulf states and other allies; for example, of the $4.5 billion **CK** increase in U.S. military costs for October 1990 compared with October 1989, $13**CK** billion, or a third in that month, was paid by other countries (*Wall St. J.*, TK). However, the phasing of the contributions is irregular: by 31 October, only $1.6 billion had been received. The State Department estimates total contributions to the U.S. will reach $10 billion, in cash and in kind **CK** , and has stated the expected sources for ~$9 billion of this—half of the total contribution from Gulf states ($12b), Japan ($4b), and Germany ($2b), the other half to go to front-line states and to repatriate stranded Kuwaiti and Iraqi workers. The period over which the contribution is to extend is uncertain and in flux, however: King Fahd, for example, offered to pay in-country costs when only 100,000 troops were contemplated, and the Emir of Kuwait pledged $600M/month only through 1990. The average contribution to the U.S. presence thus cannot be determined with much accuracy. For lack of a better basis, we simply assume that a $10 billion contribution will be received and will be amortized over a year. This assumption is probably conservative in the early months of the deployment. (In its pending supplemental request to Congress, before the November increase in deployment, DOD sought an extra $15b for Desert Shield and estimated that half of this could be raised from other nations. A net $7 1/2b contribution spread over the period August 1990 through, say, April 1991—the "weather window" plus a month's demobilization—would yield the same monthly total of $0.83b.)

On the other hand, the additional deployments announced during November 1990 imply far higher readiness and marginal costs than for CentComm alone. Although the actual costs have not yet been published, the Center for Defense Information's 24 August and 21 November 1990 memoranda, "Additional Daily Costs of Contingency Operations of Current and Future US Forces in the Persian Gulf Region, give detailed estimates totalling $31.9M/d at 100,000 (equal to Cheney's $1b/month) and $74.0M/d at 452,000 personnel. (Most of the difference is due to reserve mobilization and the increased price of oil, so to avoid double-counting of the increased U.S. oil-import bill, one must subtract from DOD's deployment costs an amount perhaps on the order of $15 [roughly the nominal price rise, at least for crude] times twice DOD's 1989 daily rate of fuel consumption [see note 32 *infra*] or $7M/d.) It therefore seems reasonable, pending official data, to assume a marginal deployment cost, per CD1, of approximately $0.97b/month for August through October and, net of the fuel-price increase, $2.04b/month for November and December.

Allocating annual costs of $46 billion for CentComm readiness to first-half-1990 Gulf imports of 2.06 Mbbl/d would yield **$61/bbl**. Marginal deployment costs for August through December 1990—assuming net Gulf imports averaged the same rate as in the first half of 1990 (they are probably lower), and using the Cheney/CDI estimate through October and the net CDI figure thereafter—would add **$22/bbl**, rising to $33/bbl thereafter at the new deployment level. Assumed contributions of $0.83b/month would subtract **$13/bbl**. These figures together, plus the **~$30+/bbl** spot price, thus exceed **$100/bbl**. (For comparison, CentComm readiness and naval marginal costs for escorting Kuwaiti tankers in the Gulf in FY1985 cost ~$468/bbl imported from the Gulf, bringing the total cost of Gulf oil at that time to ~$495/bbl, simply because Gulf imports were then only 15% as large as in the first half of 1990. See Terry Sabonis Chafee, "Projecting U.S. Military Power. Extent, Cost and Alternatives in the Gulf," September 1987 paper to 37th Pugwash Conference, Gmunden, Austria, Rocky Mountain Institute, 7 pp. Interestingly, in that operation, codenamed Earnest Will, the U.S. paid 40% of the direct marginal cost of the naval deployment.) Naturally, the outbreak of war would enormously increase these costs; total monetary-cost estimates on the order of $1 trillion have been authoritatively mentioned.

[30] Based on the previous note, an annual expenditure of $46b/y for CentComm readiness prorated for 5/12ths of the year, plus $7 billion for deployment, plus an addback of $0.4b ($7M/d for extra DOD fuel costs previously subtracted from the November-December deployment costs) would be $26.6 billion, less assumed contributions of $4.2b, equals a net cost of $22.4b for that five-month period.

[31] Assuming an average measure life of 20 years, the $2 1/2/bbl (1986 $) average levelized cost of the ~80% savings shown on the attached supply curve implies an up-front cost of $32.15/bbl-y. Investing $22.4 billion (note 29) once, at this specific cost, would save 698 million bbl/y or 1.91 Mbbl/d. Although this is 7% less than first-half-1990 gross Gulf imports of 2.06 Mbbl/d, the difference—and the 1986-90 deflator—is far more than made up by a major methodological conservatism: that one would in practice buy the cheapest savings first, rather than paying the average cost of a saving nearly sevenfold as large. As the attached supply curve shows, savings totaling several times larger than the 12% required to displace Gulf imports can be obtained at negative or zero marginal cost, not $2 1/2/bbl.

[32] In 1989, DOD used 1.492 q of primary energy including 1.035 q of petroleum (*AER:*29). Converting the fuel types shown there to physical volumes by using the appropriate energy coefficients (*MER:*130) suggests a flow of approximately 0.467 Mbbl/d, or -38% of 1989 imports of 1.224 Mbbl/d from Saudi Arabia (*MER:*50).

[33] This estimate was published earlier by USDOE, *Energy Security: A Report to the President of the United States*, March 1987, p. 9. It implies—especially given the globe-spanning logistics of resupply to the Gulf—that DOD might end up using, if it fought in the Gulf, a substantial fraction of the energy the U.S. was getting from the Gulf.

[34] Quoted from a popular newsmagazine and press reports in autumn 1990 (TK). The M-1 is understood to be more fuel-efficient per pound than a VW Beetle, but of course has far more pounds.

[35] Personal communications from experts at the Naval War College, 11 September 1990.

[36] This is not to say, of course, that the *region* is irrelevant. The United States has other interests there, such as Israel, territorial integrity, and the containment of weapons of mass destruction. Each of these should be considered on its merits, and is best considered free from the distraction of oil dependence. For detailed treatments, for example, of the nuclear proliferation issue, see A.B. & L.H. Lovins & L. Ross, "Nuclear Power and Nuclear Bombs," *Foreign Affairs* 58:1136ff & 59:172ff (1980); A.B. & L.H. Lovins, *Energy/War: Breaking the Nuclear Link*, Harper & Row Colophon, NY, 1981; and P. O'Heffernan, A.B. & LH. Lovins, *The First Nuclear World War*, Wm. Morrow, NY, 1983. We concluded there that proliferation cannot be prevented except within the context of widespread (if not universal) military and civilian denuclearization.