ABATING AIR POLLUTION AT NEGATIVE COST VIA ENERGY EFFICIENCY

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A single 18-watt compact fluorescent lamp, producing the same light as a 75-watt incandescent lamp for about 13 times as long, will over its 10,000-hour nominal lifetime avoid the emission from a typical U.S. coal-fired power plant of about one tonne of CO_2 and eight kilograms of SO_2, plus NO_x, heavy metals, and other pollutants. If the fluorescent lamp is displacing nuclear power instead, it will typically avoid producing one-half a curie of strontium-90 and cesium-137, plus approximately 25 milligrams of plutonium equivalent in explosive power to 385 kilograms of TNT. If it is displacing an oil-fired plant (now very uncommon in the U.S.), it will typically avoid burning about 200 litres of oil, which is enough to run a U.S. family car for a thousand miles, or to run a superefficient prototype car coast-to-coast and back.

All these calculations include distribution losses and net space-conditioning effects. Yet far from costing extra, the lamp will save about $20 worth of ordinary lamps and their installation labor, plus about $20-30 worth of utility fuel. This is far more than its approximate $5-8 production cost or $12-18 retail price. Thus, the lamp cleans up the air while creating tens of dollars' net wealth and deferring hundreds of dollars' investment in electrical supply systems.

This illustrates a wider theme. Although abating urban smog, acid precipitation, global warming, and other results of air pollution is commonly assumed to require costly technological investments or inconvenient lifestyle changes or both, new developments in efficient end-use of energy can now reduce emissions even more at zero or negative net internal cost to society, while providing unchanged or improved services to consumers.

These developments are in four main areas: efficient end-use technologies, ways to finance and deliver them, regulatory reform, and cultural change within energy-supplying institutions. These are summarized here in the context of saving electricity, because: (1)each unit of electricity saved at the point of use saves about 3-4 units (or, in socialist and developing countries, 5-6 units) of fuel, mainly coal, at the power plant; (2)power plants accordingly emit about a third of the CO_2 and NO_x and two-thirds of the SO_x released by combustion; (3)electricity, being the costliest form of energy (one cent/kilowatt-hour is equivalent in heat content to oil at $17/barrel), is the most lucrative form to save; and (4)electric supply systems' enormous capital intensity (two orders of magnitude more than for traditional oil-and-gas systems) gives electric efficiency unrivalled leverage in freeing resources for other needs of global development.
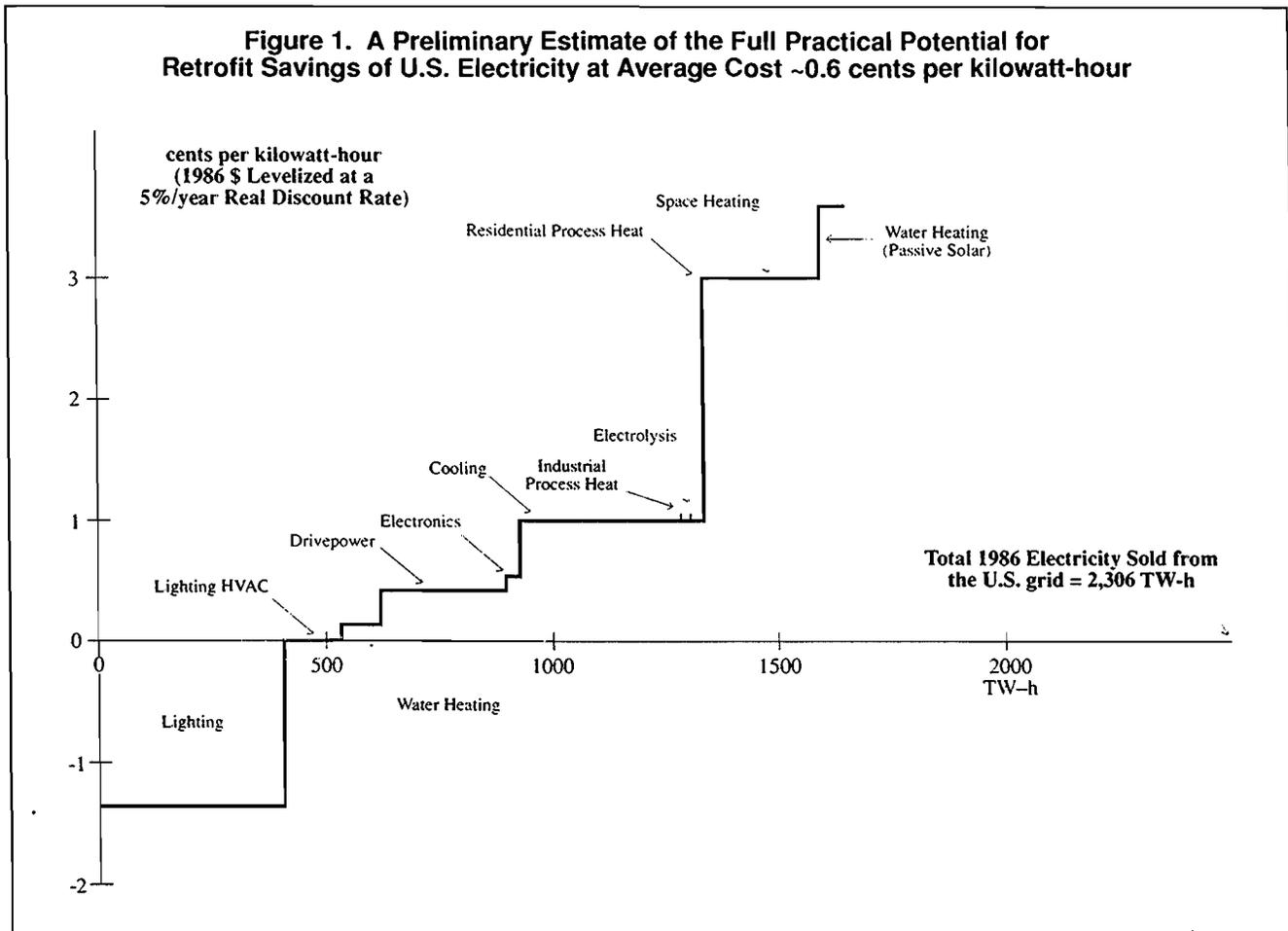
Electricity-Saving Technologies

Most of the best electricity-saving technologies now on the market were not on the market a year ago. Twice as much electricity can be saved by technical improvements today as was possible five years ago, and at only a third the real cost. This represents a sixfold expansion of cost-effective potential in the past five years and a nearly thirtyfold expansion in the past ten years.

The full potential savings available by completely equipping U.S. buildings and industries with the best technologies now commercially available has been carefully calculated from measured cost and performance data (Rocky Mountain Institute, 1990). This assessment is highly disaggregated, takes account of synergisms, and relies upon a thorough characterization of the benefits of the most modern options. Most previous analyses are highly aggregated (hence neglecting many small terms), ignore synergisms, and count only some of the effects of a short list of obsolete and inferior technologies.

The resulting potential is summarized in Figure 1, which is a neoclassical supply curve relating the marginal savings available from full retrofit (grouping, for convenience, all savings

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Figure 1. A Preliminary Estimate of the Full Practical Potential for Retrofit Savings of U.S. Electricity at Average Cost ~0.6 cents per kilowatt-hour

cents per kilowatt-hour
(1986 $ Levelized at a
5%/year Real Discount Rate)

Space Heating

Residential Process Heat

Water Heating
(Passive Solar)

Electrolysis

Cooling
Industrial
Process Heat

Electronics

Drivepower

Lighting HVAC

Total 1986 Electricity Sold from
the U.S. grid = 2,306 TW-h

500   1000   1500   2000
TW-h

Water Heating

Lighting

available from each end-use into a single package) to their levelized marginal cost of saved energy in 1986 U.S. dollars levelized at a 5 percent per year real discount rate. Cost of saved energy equals installed capital cost (corrected if necessary for any change in present-valued maintenance cost to customers) divided by the discounted stream of lifetime kilowatt per hour savings. The net cost of lighting retrofits is negative because the new equipment's approximately ten times longer lifetime reduces maintenance cost by more than the entire capital cost. Consequently, Figure 1 shows a full practical potential to save about half of U.S. electricity at zero net cost, or three-fourths at a cost averaging approximately 0.6 cent per kilowatt-hour. This is many times cheaper than operating an existing thermal power station, even if building it cost nothing. Evidence is emerging that the corresponding efficiency potential in Europe and Japan is probably not much smaller, and in socialist and developing countries is probably even larger.

In round numbers, a fourth of U.S. electricity can now be saved in lighting, a fourth in motor systems, and a fourth elsewhere (in building shells, appliances, and other equipment). The lighting saving, remarkably, is approximately 92% while producing the same amount of light (but it looks better and one can see better), at a net internal cost of about minus 1.4 cents per kilowatt-hour. The main technologies are replacing incandescent lamps with compact fluorescents, and retrofitting fluorescent fixtures with specular imaging reflectors, continuously dimmable high-frequency ballasts, tristimulus-phosphor lamps, and improved lenses, controls, and maintenance. Such retrofits are the key to the service sector, where lighting directly and indirectly uses approximately 60 percent or more of total electricity and the corresponding cost savings typically exceed $10 per square meter per year with paybacks of less than 2 years.

Electric savings nearly as large are available in household appliances and residential building-shell retrofits, at costs ranging up to a few cents per kilowatt-hour and often rapidly falling. In motors and associated components, which use over half the world's electricity (more primary energy than highway vehicles), systematically applying 35 classes of improvements can save typically approximately 50 percent at costs averaging less than 0.5 cents per kilowatt-hour.

An electric utility which gave away the measures summarized in Figure 1 would earn lower electric revenues, but its costs would decline even more, because the electricity is saved more cheaply than it can be made in existing plants. This represents an avoided operating cost of typically several

cents per kilowatt-hour in the short run and several times that in the long run, plus any externalities.

Implementation

Ways to finance and deliver these new efficiency technologies have evolved as quickly as the hardware itself. Proper pricing of electricity, though important, only weakly promotes efficient investment, since customers' typical discount rate is roughly ten times that of utilities, so unaided customers will only buy efficiency costing about a tenth of the tariff they avoid. But many U.S. electric utilities already overcome this "payback gap" by helping customers become more efficient through information, technical assistance, concessionary loans, leases, rebates, and gifts. Extensive and generally encouraging empirical data are available on the size, speed, cost, persistence, and reliability of the resulting savings, and on proven ways to plan, market, and evaluate them.

A dozen more innovative financing methods are now showing even greater promise: in effect, they make a market in "negawatts," transforming saved electricity into a commodity that can be traded across time and space and which is subject to competitive bidding, arbitrage, derivative instruments, and secondary markets (Lovins, 1989a). These new methods hold promise of even bigger, cheaper, faster savings than the older methods, which themselves can be highly successful. For example, if all Americans saved electricity at the same speed and cost at which ten million Southern Californians actually did save electricity in the mid-1980s, then the forecast long-term need for U.S. power supplies would fall by 40 gigawatts per year. Absolute demand could fall by several percent per year while GNP grew at a similar pace. The utilities' program cost to achieve that saving would approximate 0.1-0.2 cents per kilowatt-hour, or about one percent of the cost of new power plants. More directly targeted approaches, such as mass retrofits of commercial lighting systems, could plausibly save approximately 20 percent of a typical utility's current sales in just a few years, if desired.

Regulatory and Cultural Change

In every U.S. state except California, utilities generally earn more profit by selling more electricity and less profit by selling less, while customers capture 100 percent of any bill reduction achieved. These perverse effects of traditional regulation are now starting to be corrected as states implement the unanimous July 1988 agreement-in-principle by the Conservation Committee of the National Association of Regulatory Commissioners that utilities' profits should be decoupled from their sales, and that if they do something which cuts customers' bills, utilities should in effect be allowed to keep part of the resulting saving as extra profit, thereby creating a direct incentive for efficient behavior.

These reforms will undoubtedly speed the already rapid cultural evolution of utilities from a top-line to a bottom-line orientation, from business-as-usual to entrepreneurship, and

from kilowatt-hour vendors to energy-service-market competitors seeking the profitable production of customer satisfaction. These changes are not easy, but they do appear to be much easier than the alternative.

Using Efficiency to Pay for Cleanups

Fuels which are not mined and burned have no environmental impacts. Whenever it costs less to save fuels than to burn them, the environmental impacts associated with obtaining, converting, and using them can be abated at negative net internal cost to society.

For example, rather than raising people's electric bills to scrub dirty coal plants' flue gas, one can use well-established delivery methods to help the same customers get super-efficient lights, motors, appliances, and building components. They will need then less electricity to obtain the same services, so the utility can burn less coal and emit less sulfur (preferably using "environmental dispatch" to back out the dirtiest plants first). But the main effect will be to save the utility a great deal of money, because efficiency is cheaper than coal. The utility then can use part of this saved operating cost to clean up the remaining plants by any method of its choice, part to cut its tariffs, and part to reward its investors for having hired such smart managers. On very conservative assumptions, one analysis of this approach found that the Midwest region responsible for a third of all U.S. power-plant sulfur emissions could achieve a 55 percent SO_x reduction at a net-present-valued 1985-2000 cost of minus approximately $4-7 billion, rather than the plus $4-7 billion for normal abatement at constant electric demand (Geller, 1987). This represents a net saving of approximately $11 billion.

The same efficiency investments also abate CO_2. For example, the Swedish Power Board has published a plan to support 50 percent GNP growth, phase out nuclear power (two-fifths of Sweden's power supply), yet simultaneously reduce the heat-and-power sector's CO_2 emissions by a third and make electrical services cheaper, by combining electric end-use efficiency improvements, fuel-switching, and environmental dispatch (Johansson, 1989).

The same approach applies globally. A 1981 long-term analysis for the German Federal Environmental Agency (Lovins et al., 1981) assumed arguendo a world with eight billion people, uniformly industrialized to the level of the Federal Republic of Germany in 1973 (when it was the most heavily industrialized country on earth, and one of the most energy-efficient): nearly a fivefold increase in the 1975 Gross World Product, with tenfold growth in the developing countries. Nonetheless, if such a world used energy in a way that saved money at 1980 technologies and prices, its total primary energy use would be a third of the 1989 level. Moreover, each major region could get essentially all it needed of each type of energy from renewable sources, which in 1980 were already available and cost-effective on the long-run margin. The resulting atmospheric CO_2 level in 2030 would be approximately 360 ppm, rising by 5 ppm every three

decades or so, compared to standard high-energy scenarios' approximately 450 ppm, rising by 50 ppm every decade or so.

While this high-efficiency scenario is necessarily somewhat idealized, its implementation over some decades would require only a rate of efficiency improvement (and, for some countries like the U.S., renewable-supply deployment) somewhat below that actually achieved since 1973. For example, during 1979-86, the U.S. obtained more than seven times as much new energy from savings as from all net expansions of energy supply, and of those expansions, more from renewables than from nonrenewables.

Oil-Efficiency Analogies

Figure 2 summarizes the approximate potential to save about four-fifths of U.S. oil (including substitutions of saved gas for oil), with another fifth worth of saved gas left over, at an average cost of less than $3 per barrel, by fully using the best technologies already demonstrated, roughly half of which are now on the market (Lovins, 1989b).

The most surprising and important technology shown is the 3.3 litres per 100 km (71 mi/gal) car which Volvo claims to be able to make at zero marginal capital cost. A similar claim by Peugeot at 2.6 litres per 100 km (92 mi/gal) would add a further five percentage points' savings. Prototype cars al-

ready tested by these and other manufacturers (none of which has published a marginal production cost) variously combine superior safety and peppiness with low emissions and normal comfort levels over a range of on-road composite efficiencies of 1.7-3.5 litres per 100 km (67-138 mi/gal).

Although emissions from such cars will probably not decline linearly with their fuel intensity, major reductions are bound to occur, at a negative cost equal to the difference between the superefficient cars' marginal capital cost, if any, and the present-valued cost of the fuel they save. This adds an important option to Figure 3, a Lawrence Berkeley Laboratory supply curve for abating NO_x in the Los Angeles Basin (Akbari et al., 1989). Simple electricity-saving measures in the basin (in this case, based on reducing the urban heat island) were projected to save a few percent of the NO_x emissions at a cost so strongly negative that the saved money could pay for most of the South Coast Air Quality Management District's proposed abatements plus additional measures such as tripled car-catalyst rhodium. This represents an approximate 30 percent abatement at zero net cost. But adding a further abatement by superefficient, zero-marginal-capital-cost, therefore negative-total-cost cars, which is a new block of reductions to be inserted just to the right of the electrical saving, would presumably increase the total abatement to very high levels (perhaps around 80 percent) at a

Figure 2. Technical Potential to Save U.S. Oil Consumption

Figure 3. Supply Curve for Abating NO$_x$ in the Los Angeles Basin
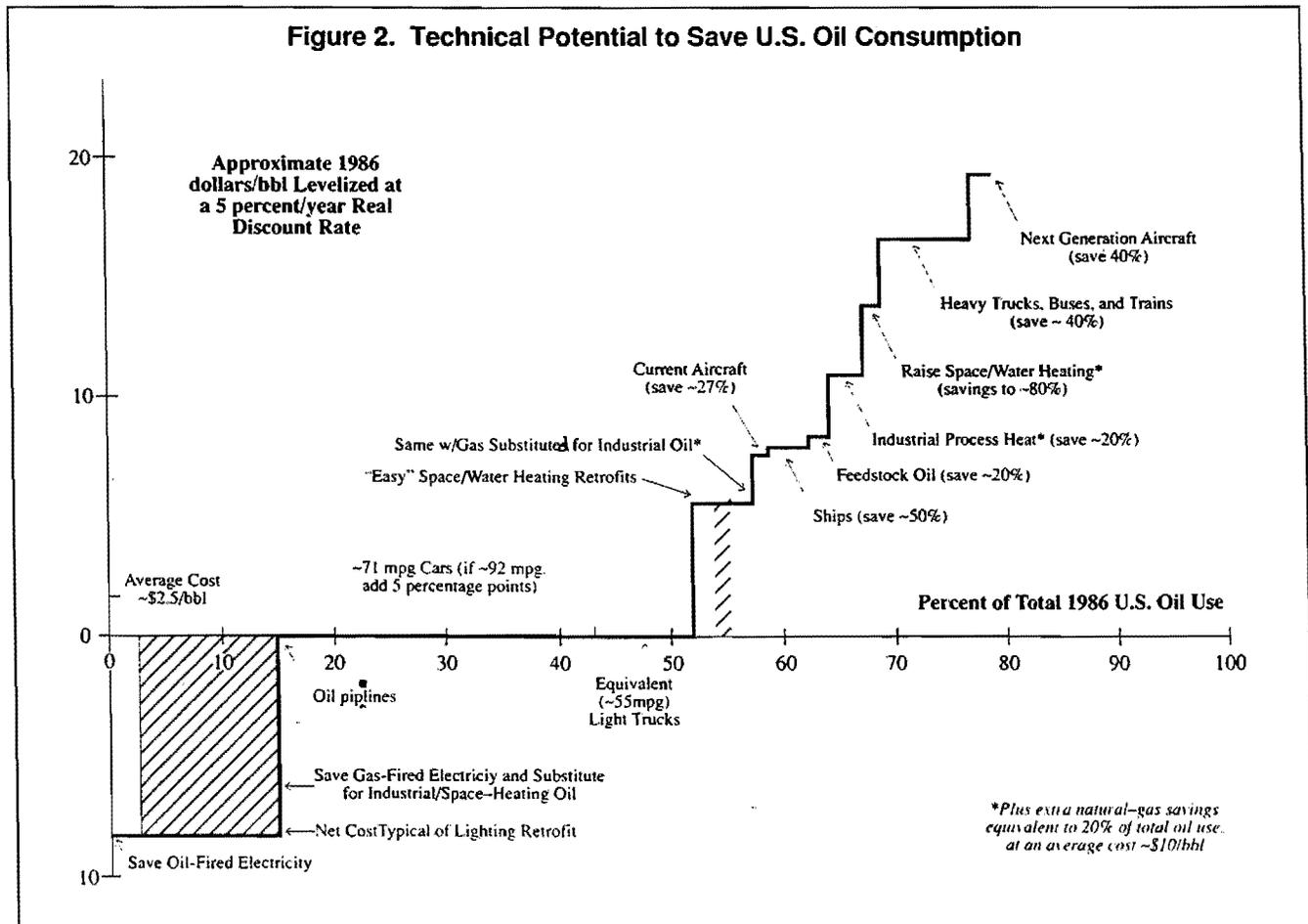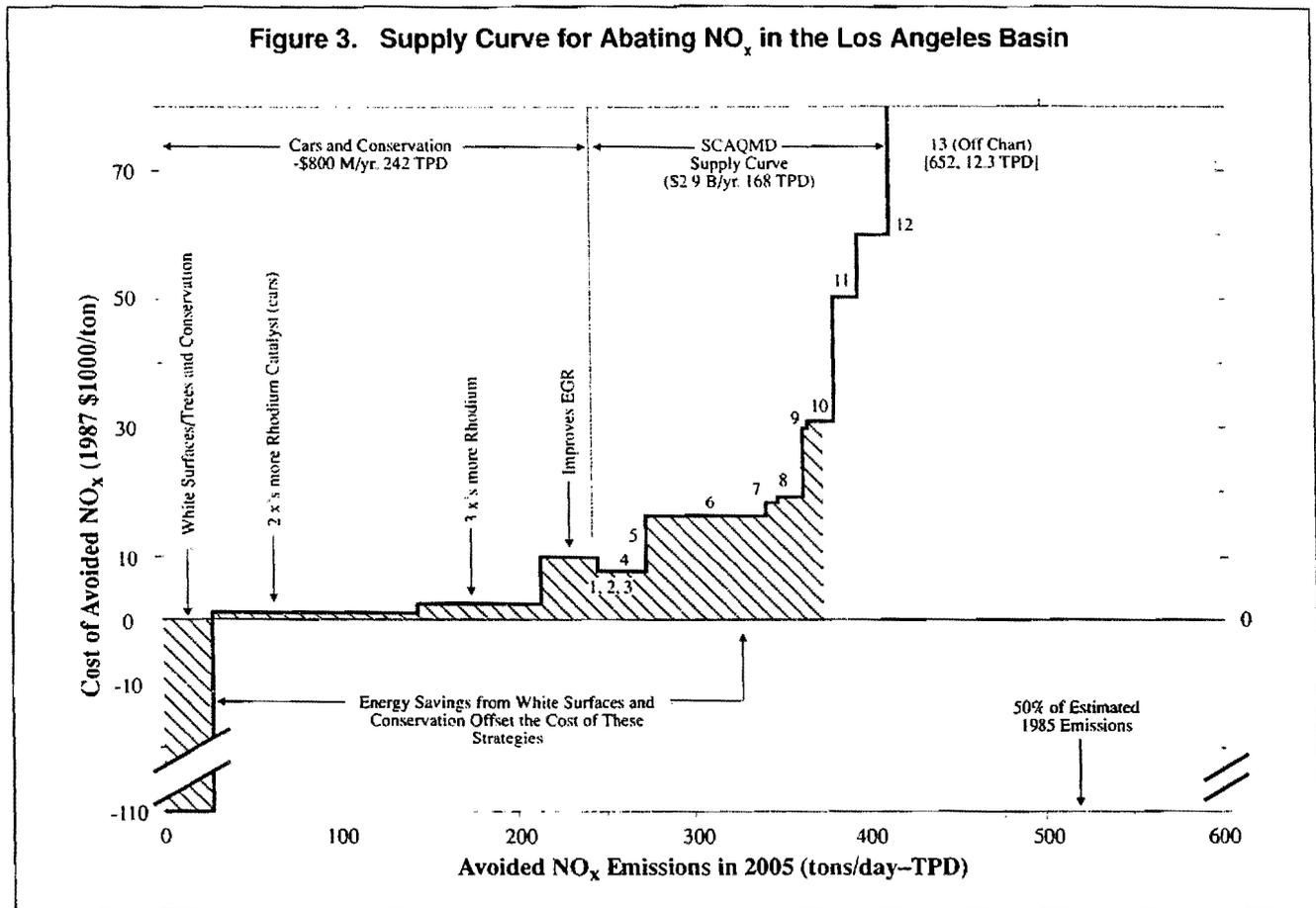
negative total cost. Similar considerations would apply to all other cost-effective ways to displace fuel-burning with end-use efficiency.

Conclusions

Whether for energy-derived NO$_x$ in Los Angeles, SO$_x$ in Ohio, or CO$_2$ anywhere, advanced techniques for energy end-use efficiency can pay for very large direct and indirect reductions in emissions, usually with money left over. This permits much more complete abatements than are often analyzed, and not at a cost but at a large profit.

The order of economic priority, however, is also the order of environmental priority. Choosing the best buys first maximizes abatement per dollar; choosing anything else first thus reduces abatement per dollar. In this opportunity-cost sense, nuclear power makes global warming worse by diverting investment away from electric end-use efficiency, which would displace far more coal-burning per dollar spent (Keepin and Kats, 1988). To achieve the largest, fastest abatement therefore requires that the "Chinese-restaurant-menu" approach to energy investments, buying one option from Column A, one from Column B, etc., until all constituencies are satisfied, give way to the least-cost approach that is now the expressed (if less often the observed) policy of utility regulators in more than 40 states. The powerful supply-curve

method of identifying priorities is therefore valid only if pollution prevention is considered together with, and allowed to precede and even displace as well as to augment, the more traditional "end-of-pipe" technologies.

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