## Chapter 2

# Why Support Alternative Fuels?

During the oil crises of the 1970s, support for alternative highway fuels focused primarily on the issue of energy security and the United States' growing dependence on imported crude oil and petroleum products. Recent support for alternative fuels has centered around efforts to attain urban air quality goals and the automobile's central role as a source of air emissions. Achievement of air quality goals have been frustrated by steadily growing demand for travel and the increasing difficulty of squeezing further emission reductions from gasoline vehicles already subject to stringent controls. Environmental officials and legislators—lead especially by State and local organizations in California and recently joined by the Bush Administration-view the use of 'clean fuels' as a promising way to begin a new cycle of atmospheric cleanup. They also foresee a secondary benefit from potential reductions in toxic air emissions from fuel production and distribution.

In addition, the old concerns about energy security are still with us and are increasing, and a new problem—global warming from increases in atmospheric concentrations of so-called "greenhouse gases"—has surged to the front of concern for the environment. Concern about both of these problems has played a role in the debate over alternative fuels.

This chapter reviews briefly each of these three concerns, to lay the foundation for judging the need for alternative fuels and the attractiveness of a strong government role in introducing these fuels. Readers familiar with these concerns may wish to skip this chapter and move to the chapters on the individual fuels.

## OZONE CONTROL IN PERSPECTIVE

Within the next year, Congress must reauthorize--and, some believe, rethink-the Clean Air Act. The mechanism established in 1970 to assure the Nation's air quality has failed notably to reach health-based standards for a major pollutant, ozone, in much of the country. Today, almost two decades after the Act's original passage, about 70 to 100 urban areas (depending on weather conditions) still violate the ozone standard; indeed, the intense heat of summer 1988 added an estimated 28 new names to the list of "nonattainment" cities. Currently available control methods are not adequate to bring all of these cities into compliance. This third attempt to craft an ozone control program thus raises several controversial issues: how great a threat ozone poses to human health, agricultural production, and environmental welfare; what technical measures to take against this hard-to-control pollutant; how to alter deadlines, sanctions, and planning mechanisms; how to deal with the cities that cannot meet the standard with any existing or near-term means; and finally, how to encourage development of new control methods so that continued progress can be made.

Since 1970, a Federal-State partnership has been in place to handle ozone control, with the Environmental Protection Agency (EPA) setting nationally uniform ambient air quality standards and the States, with the Agency's help and approval, working to meet them. Based on ozone's known health effects, the standard is currently set at a peak, l-hour average ozone concentration of 0.12 parts per million (ppm). Any area experiencing concentrations exceeding the standard more than once per year, on average, is declared a nonattainment area. EPA updates the nonattainment list annually, as data become available. The list in 1988 included cities housing well over half of the American population.

One suggested strategy for reducing urban ozone is the substitution of alternative fuels for gasoline in the highway vehicle fleet. Each of the suggested alternative fuels--methanol, ethanol, natural gas, hydrogen, electricity, and reformulated gasoline--have, to a differing degree, the potential to reduce either the emissions of the volatile organic compounds that are the precursors of ozone, or the reactivity of these emissions (that is, their likely contribution to ozone formation per unit of mass). The Administration's ozone control strategy relies heavily on alternative fuel use by highway vehicles,

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[1] This section is adapted from the summary chapter, U.S. Congress, Office of Technology Assessment, *Catching OurBreath: Next Steps in Reducing Urban Ozone, OTA-O-412* (Washington, DC: U.S. Government Printing Office, July 1989).

and the State of California, whose ozone problems are the United States' most severe, also supports alternative fuels, though its latest control strategy does so indirectly by mandating the sale of ultra-low-emission vehicles. Under the Administration's proposal, EPA must promulgate performance standards for alternatively fueled vehicles 18 months after enactment. EPA has stated that the initial standards are likely to be equivalent to the benefits achieved by flexibly fueled vehicles burning M85[2] (according to EPA, their benefit is equivalent in ozone forming potential to a 30 percent reduction in hydrocarbon emissions from vehicles meeting proposed hydrocarbon standards and operating on low volatility gasoline, with Reid Vapor Pressure of 9.0[3]). EPA anticipates that performance standards by the year 2000 or so can be set equivalent to the benefits achieved by dedicated M100[4] vehicles (which EPA believes are equivalent to about an 80 percent reduction in passenger car hydrocarbon emissions, relative to the proposed standards and low volatility gasoline). The proposal requires that 8.75 million alternatively fueled vehicles must be sold in the nine worst nonattainment areas (those with peak ozone concentrations of 0.18 ppm or higher) between 1995 and 2004. The proposal also gives EPA the authority to mandate adequate supplies of fuel to operate the vehicles and requires that the State make the sale of the fuel "economic." In California, both the South Coast Air Quality Management District (covering the Los Angeles area) and the California Air Resources Board have stated their intent to adopt an emissions control program likely to force large-scale use of alternatively fueled vehicles. The purpose of this section is to place these proposed measures into perspective, by describing ozone's impact on U.S. air quality and the available range of options for reducing ozone concentrations.

### Why Control Ozone?

**The** 0.12 ppm national standard for ozone derives from solid evidence of the health effects of short-term exposure above that level, as illustrated in figure 2-1. Excessive ozone is harmful to people. Some healthy adults and children experience coughing, painful breathing, and temporary loss of some lung function after about an hour or two of exercise at the peak concentrations found in nonattainment cities.

Does the current standard adequately protect people who are exposed for long periods or at high exercise levels? Experts are unsure. Several studies over the past 5 years have shown temporary loss of some lung function after an hour or two of exposure at concentrations between 0.12 and 0.16 ppm, among moderately to heavily exercising children and adults. And despite the current standard's emphasis on a l-hour peak, real-life exposures to near daily maximum levels can last much longer; ozone levels can stay high from mid-morning through late afternoon. With exposure during 6 hours of heavy exercise, temporary loss of some lung function can appear with ozone levels as low as 0.08 ppm.

Potentially more troubling and less well-understood are the effects of long-term, chronic exposure to summertime ozone concentrations found in many cities. Regular out-of-doors work or play during the hot, sunny summer months in the most polluted cities might, some medical experts believe, cause biochemical and structural changes in the lung, paving the way for chronic respiratory diseases. To date, though, evidence of a possible connection between irreversible lung damage and repeated exposure to summertime ozone levels remains inconclusive.

Clear evidence shows that ozone damages economically, ecologically, and aesthetically important plants. When exposed to ozone, major annual crops produce reduced yields. Some tree species suffer injury to needles or leaves, lowered productivity, and in severe cases, individual trees can die. Important tree species are seriously affected in large areas of the country. In the most heavily affected forested areas, such as the San Bernardino National Forest in California, ozone has begun altering the natural ecological balance of species.

Whether or not the current standard is adequate, many areas of the country have failed to meet it. About half of all Americans live in areas that exceed

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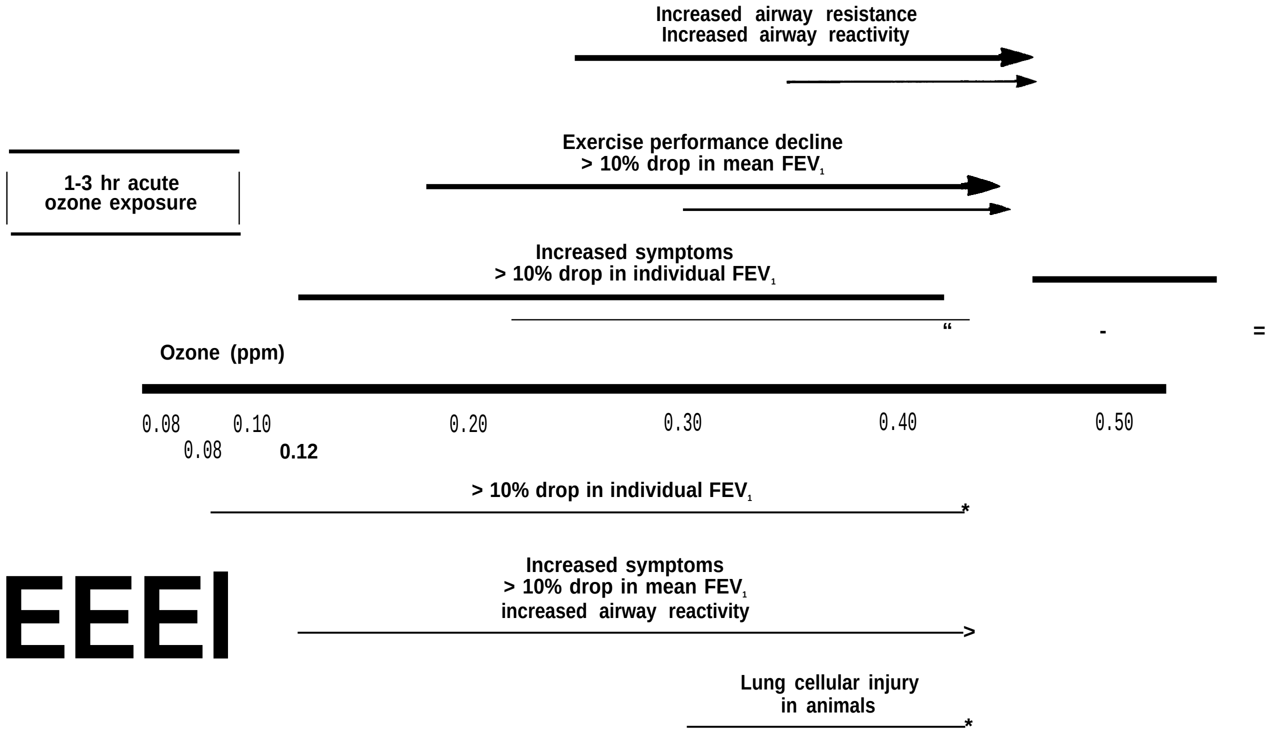
[2] M85: a mixture of 85 percent methanol and 15 percent gasoline.

[3] U.S. Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Methanol as an Automotive Fuel*, Special Report, Office of Mobile Sources, September 1989.

[4] M100: 100 percent methanol fuel.

[5] Ibid.

Figure 2-l—Acute Effects of Ozone Exposure



Effects above the ozone concentration line are from 1 to 3 hour exposures to ozone. Effects below the line are from 4 to 8 hour exposures. FEV, (forced expiatory volume in 1 second) is a measure of lung function. The bolder arrows indicate the range of concentrations at which effects occur from exposure while exercising heavily; the lighter arrows indicate the concentrations at which effects occur while exercising moderately. Effects begin at the concentration indicated by the tail (left side) of the arrow.

SOURCE: Office of Technology Assessment, 1989.

the standard at least once a year. About 100 " nonattainment areas" dot the country from coast to coast, with ‘‘design values” —a measure of peak ozone concentrations-ranging from 0.13 ppm to as high as 0.36 ppm. Half the areas are fairly close to attainment, with design values up to 0.14 or 0.15 ppm; for these areas, reaching the standard is probably feasible with existing technologies. However, the remaining areas, including the Nation’s worst violator, Los Angeles, present much more serious and challenging problems, with design values in excess of 0.16 ppm. Sixty of the 317 urban and rural areas for which we have data had at least 6 days/year between 1983 and 1985 with ozone levels exceeding 0.12 ppm for 1 or more hours. A number of areas topped the standard for 20 or more days, with the worst—Los Angeles-averaging 275 days per year.

Ozone in a city’s air, however, does not necessarily equal ozone in people’s lungs. Concentrations vary with time of day and exact location. People vary in the amount of time they spend indoors, where concentrations are lower. And the more actively someone exercises, the more ozone he or she inhales. Each year, nationwide, an estimated 34 million people are actually exposed to ozone above 0.12 ppm at low exercise levels, and about 21 million are exposed during moderate exercise, on average about 9 hours per year. About 13 million people are exposed to ozone above 0.12 ppm during heavy exercise, each of them for about 6 hours each year, on average. At each exercise level, one-quarter of these people live in the Los Angeles area.

## *Ozone and Its Precursors*

Ozone is produced when its precursors, volatile organic compounds (VOCs) and nitrogen oxides ($NO_x$), react in the presence of sunlight. VOCs, a broad class of pollutants encompassing hundreds of specific compounds, come from manmade sources including automobile and truck exhaust, evaporation of solvents and gasoline, chemical manufacturing, and petroleum refining. In most urban areas, such manmade sources account for the great majority of VOC emissions, but in the summer in some regions, natural vegetation may produce an almost equal quantity. $NO_x$ arises primarily from fossil fuel combustion. Major sources include highway vehicles, and utility and industrial boilers.

Ozone control efforts have traditionally focused on reducing local VOC emissions, partly because the relevant technologies were thought to be cheaper and more readily available. In addition, under some conditions at some locations, reducing $NO_x$ can have the counterproductive impact of increasing ozone concentrations above what they would be if VOCs were controlled alone.[6]

Local controls on VOC emissions cannot completely solve the Nation's ozone problem, however. In many places, even those with good control of their local emissions, reducing ozone is complicated by the 'transport' of pollutants, as ozone or precursors originating elsewhere are carried in by the wind. "Plumes' of elevated ozone have been tracked 100 miles or more downwind of some cities: the Greater New York area's plume, for example, can extend all the way to Boston. Over half of the metropolitan areas that failed to attain the ozone standard between 1983 and 1985 lie within 100 miles downwind of other nonattainment cities. In such cases, VOC (and sometimes $NO_x$) reductions in the upwind cities could probably improve air quality in their downwind neighbors. Indeed, reductions in certain areas that are themselves already meeting the standard might also aid certain downwind nonattainment areas.

The significance of transported pollutants varies substantially from region to region and day to day. During severe pollution episodes lasting for several days, for example, industrial or urban $NO_x$, or ozone pollution can contribute to high ozone levels hundreds of miles away. In certain heavily populated parts of the country, pollution transport is a significant and very complex problem. The northeast corridor, from Maine to Virginia, contains 21 nonattainment areas in close proximity; California, 8; the gulf coast of Texas and Louisiana, 7; and the Lake Michigan area, 5. Figure 2-2 shows the location of nonattainment areas.

Aside from pollution transport, the balance of VOCs and $NO_x$ in the atmosphere is another complicating factor in controlling urban ozone levels. The precise local balance of VOCs and $NO_x$ varies from place to place, even within the same metropolitan area, and from day to day. Where the concentration of $NO_x$ is high relative to VOCs, for example, in urban or industrial centers with high $NO_x$ emissions, reducing VOC emissions can effectively cut ozone because production is limited by the quantity of available VOCs. In these cases, focusing primarily on control of VOC emissions is the correct strategy for reducing ozone concentrations.

On the other hand, where the relative concentration of VOCs is high and the level of ozone is thus "$NO_x$-limited," $NO_x$ reductions must be a critical part of an ozone reduction strategy. $NO_x$-limited conditions occur in some cities and in most rural areas. As an air mass moves away from industrial districts and out over suburban or rural areas downwind of pollutant emission centers, conditions tend to become more $NO_x$-limited because $NO_x$ disappears from the air through chemical and physical processes more rapidly than do VOCs.

## *Controlling Volatile Organic Compounds*

Since 1970, reducing VOC emissions has been the backbone of our national ozone control strategy, and the Nation has made substantial progress, at least in slowing further degradation from preexisting conditions. According to EPA estimates, while VOC emissions have remained relatively constant over the last decade, they are about 40 percent lower than they would have been without existing controls. Despite this progress, however, large areas of the country have missed each of several 5- and 10-year deadlines set by Congress-first the original deadline of 1975, and again in 1982 and 1987.

Additional progress is still possible in this area. Total manmade VOC emissions, according to OTA estimates, will remain about the same for about a decade. Substantially lower emissions from cars and trucks should offset sizable increases from stationary sources. But total emissions will begin rising again by around 1995 to 2000, assuming that State and EPA regulations remain unchanged.

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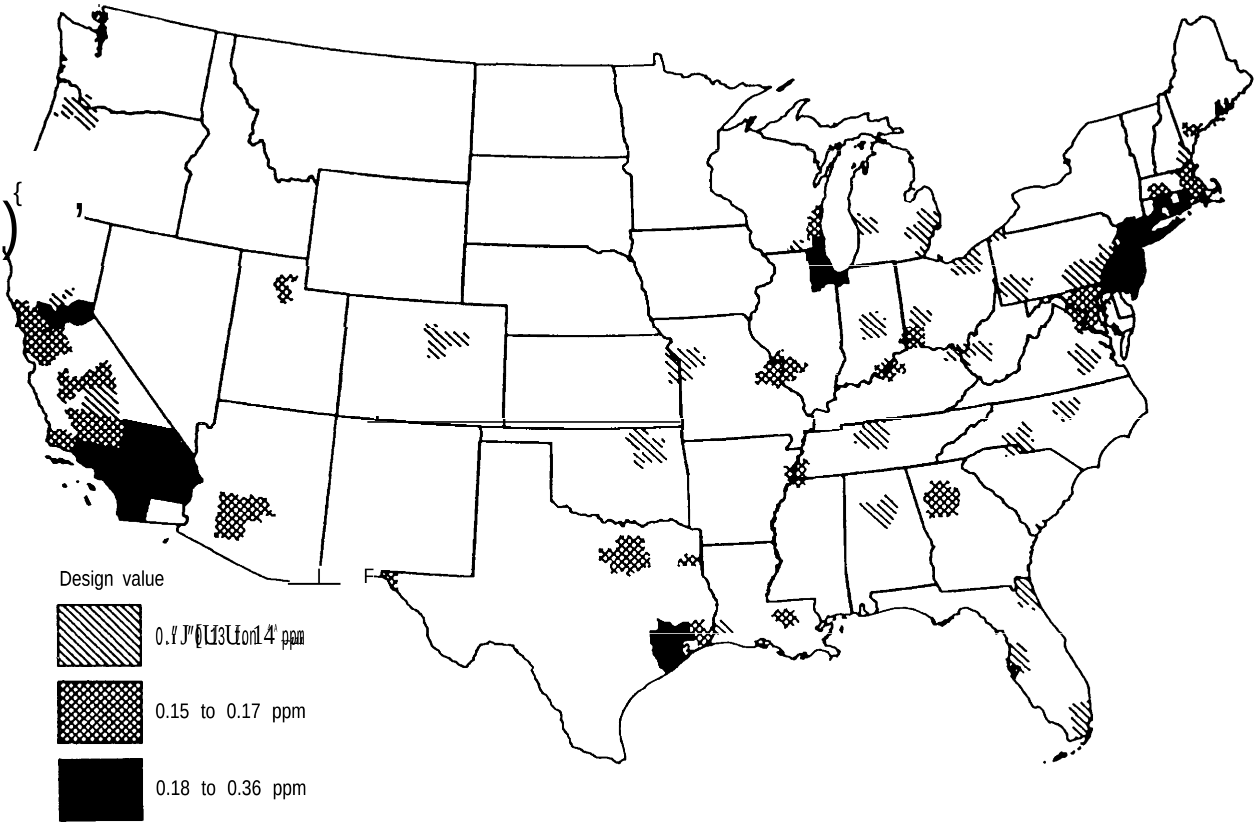
[6] Although $NO_x$ is an ozone precursor, it also can destroy ozone when $NO_x$/VOC ratios are high.

**Figure 2-2—Areas Classified as Nonattainment for Ozone Based on 1983-85 Data**



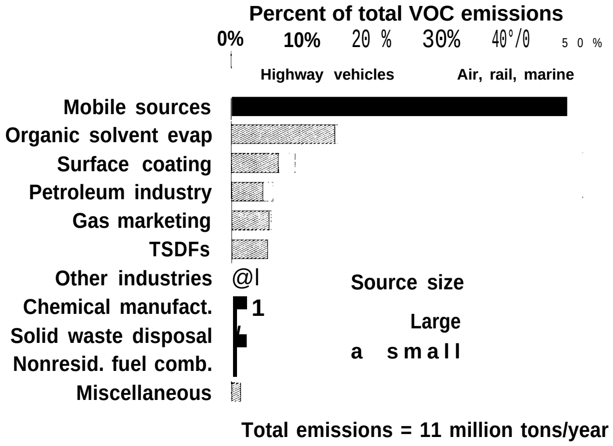
**The shading indicates the fourth highest daily maximum 1-hour average ozone concentration, or "design value," for each area.**

**SOURCE: Office of Technology Assessment, 1989.**

Today, as shown in figure 2-3, emissions from mobile sources, surface coating such as paints, and other organic solvent evaporation together account for about two-thirds of all manmade VOCs. Highway vehicles alone contribute about 40 to 45 percent of the total. The next largest category of emissions, evaporation of organic solvents, involves such diverse activities as decreasing metal parts and drycleaning, and products such as insecticides. Next come surface coatings, which include inks, paints, and various similar materials used in painting cars, finishing furniture, and other products. These sources vary in size from huge industrial installations to a person painting a chair. About 45 percent of all manmade VOC emissions originate in small stationary sources producing less than 50 tons per year; they include vapors from solvents and paints, gasoline evaporating while being pumped, emissions from printing shops and autobody repair shops, and the like.

All of the alternative fuels examined in this report have the potential to lower effective VOC emissions (either by lowering mass emissions or by producing less reactive emissions) from mobile sources by a substantial degree-on a "per vehicle basis,' some can eliminate all or virtually all of these emissions (though there may be VOC emissions from fuel production and delivery). Of course, the actual reductions in urban emissions will take place slowly, as new, alternative fuel vehicles gradually replace gasoline-fueled vehicles. Because introducing these fuels is expected to be expensive, policymakers should judge the potential costs and benefits of these fuels as compared to the potential costs and benefits of alternative methods of reducing VOC emissions.

**Figure 2-3—VOC Emissions in Nonattainment Cities, by Source Category, in 1985**



Stationary sources that emit more than 50 tons per year of VOC are included in the "Large" categories.

SOURCE: Office of Technology Assessment, 1989.

In its recent study *Catching Our Breath: Next Steps for Controlling Urban Ozone,* OTA analyzed about 60 currently available control methods that together deal with sources producing about 85 percent of current manmade VOC emissions (included among these methods is methanol in fleet use; methanol in general use and the other fuels examined in this report were not considered "currently available" in *Catching Our Breath).* We believe that the potential exists, using these various controls, to lower summertime manmade VOC emissions in nonattainment cities in the year 1994 by about 35 percent compared to the 1985 level. A reduction of this size would equal approximately two-thirds of all the reductions needed, on average, to allow nonattainment cities to meet the standard. According to our analysis, if all currently available controls are applied, total VOC emissions in the nonattainment cities will fall by about 3.8 million tons per year by 1994; the exact figure could be as low as 1.5 million tons or as high as 5.0 million tons, depending on the accuracy of our assumptions.

All cities, however, would not benefit equally from these reductions. If those with current design values (peak ozone concentrations) of 0.14 ppm were to implement all the VOC control methods we analyzed, most could achieve ozone levels at, or even below the standard. Cities with current design values of 0.16 ppm or higher would likely fall short, and in some cases far short, of the needed reductions.

Each of the 60 control methods analyzed contributes to the 35-percent reduction from 1985 levels that we foresee happening in nonattainment cities, as shown in figure 2-4. The most productive method, yielding 12 percent in reductions (about one-third of the total) on a hotsummer day, requires reducing the volatility of the Nation's motor fuels. Less volatile gasoline[7] would curtail evaporation emissions (including so-called "running losses' while the vehicle is moving) and would lower exhaust emissions. An additional 6 percent in reductions could come from stricter controls on facilities that store, treat, and dispose of hazardous wastes. Another 4 percent could come from applying all 'reasonably available control technology' (RACT-level) controls now found in *any* State's ozone control plan to *all* nonattainment areas' sources larger than 25 tons. About 40 types of sources, such as petroleum refineries, chemical manufacturers, print shops, and drycleaners, would be included.

A 2-percent reduction would come from enhanced programs to inspect cars and trucks and require maintenance of faulty pollution controls. This is over and above the reductions achieved by the inspection and maintenance programs in operation today. Modifying the nozzles of gas station pumps to trap escaping vapors (installing 'Stage II gasoline vapor recovery systems") would yield another 2-percent reduction. Installing devices to do the same job on individual vehicles as they fuel up ("onboard technology") would produce about the same reductions 8 to 10 years later, as newer cars that have the devices replace older ones that do not. (The two methods together would yield only slightly greater reductions than either method alone.) Adopting new "control technique guidelines' for smaller (but still larger than 25 tons) categories of stationary sources not already controlled in some ozone control plans, such as autobody refinishing and wood furniture coating shops, coke oven byproduct plants, bakeries, and the like, would account for an additional 1 percent. Another 0.5-percent reduction can be had in the worst nonattainment areas by requiring businesses that operate fleets of 10 or more vehicles

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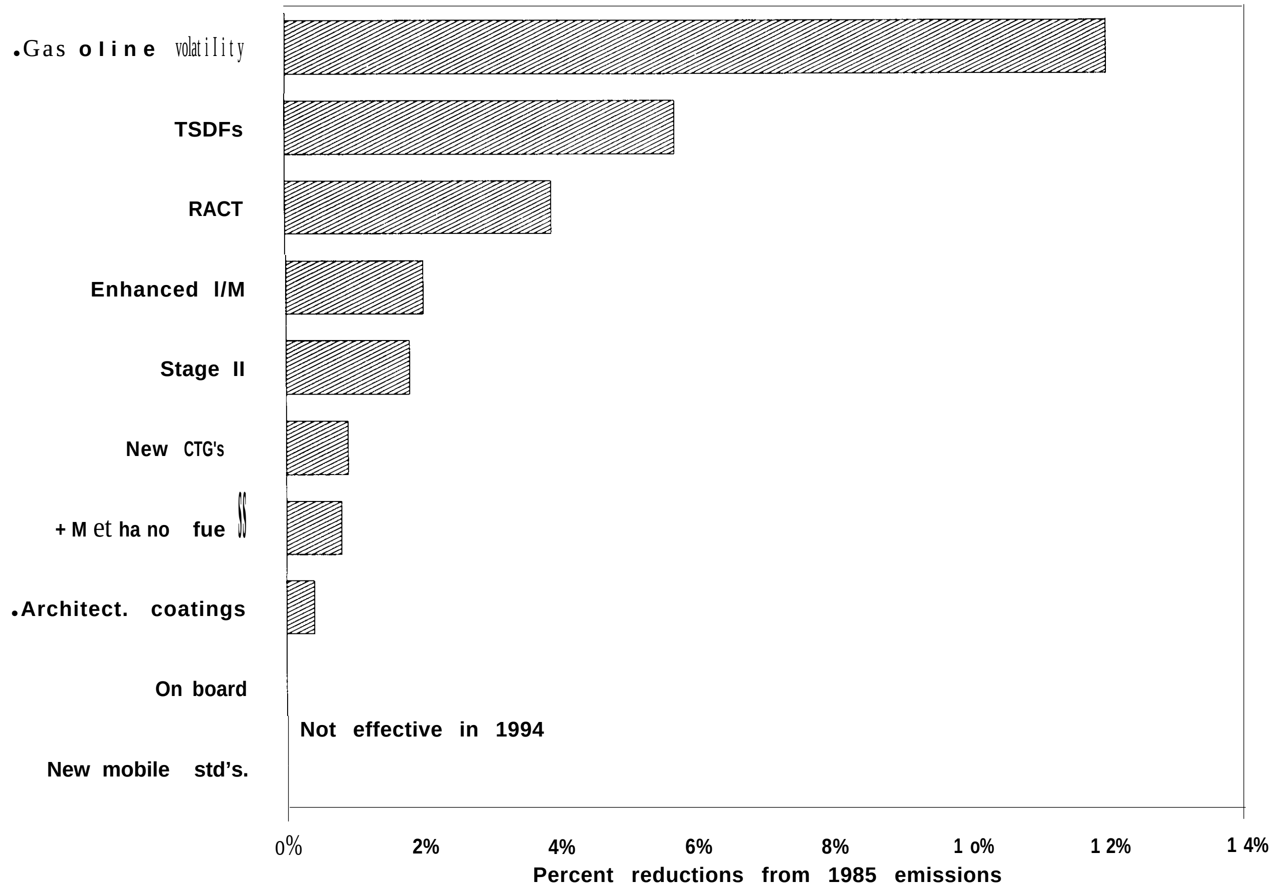
[7] In our analysis, we assume that gasoline volatility is reduced to 9 pounds per square inch (psi) Reid Vapor Pressure (RVP), nationwide, during the 5-month summertime period when ozone concentrations most often exceed the standard.

Figure 2-4—VOC Emissions Reductions in 1994 Compared to 1985 Emissions, by Control Method



•Emissions reductions also achieved in attainment areas.

+ Percent reductions only in those cities in which it is adopted.

*Strategy Descriptions*

**Gasoline volatility controls** which limit the rate of gasoline evaporation.

TSDF = controls on hazardous waste treatment, storage, and disposal facilities.

RACT = "Reasonable Available Control Technology" on all existing stationary sources that emit more than 25 tons per year of VOC.

**Enhanced inspection and maintenance (i/M)** programs for cars and light-duty trucks.

Stage ii control devices on gas pumps to capture gasoline vapor during motor vehicle refueling.

New CTGs = new Control Technique Guidelines for several categories of existing stationary sources for which no current regulations exist.

**Methanol fuels as** a substitute for gasoline as a motor vehicle fuel.

**Federal Controls on architectural surface coatings.**

**Onboard controls** on motor vehicles to capture gasoline vapor during refueling.

New **highway-vehicle emission standards** for passenger cars and light-duty gasoline trucks.

SOURCE: Office of Technology Assessment, 1989.

in those areas to substitute methanol for gasoline. Limits on the solvent content in architectural coatings such as paints and stains would lower emissions by 0.5 percent. Finally, more stringent standards for tailpipe emissions from gasoline-powered cars and light-duty trucks[8] would lower emissions by 1.5

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[8] The emission standards used in our analysis are as follows:

(in grams of pollutant emitted per mile traveled (g/mile) for non-methane hydrocarbons (NMHC) and $NO_X$)

Passenger cars—NMHC: 0.25 g/mile; $NO_X$: 0.4 g/mile
Light-duty gasoline trucks (by truck weight>
(up to 3,750 lbs) NMHC: 0.34 g/mile; $NO_X$: 0.46 g/mile
(3,751 to 6,000 lbs) NMHC: 0.43 g/mile; $NO_X$: 0.80 g/mile
(6,001 to 8,500 lbs) NMHC: 0.55 g/mile; $NO_X$: 1.15 g/mile

We assume that these standards can be met during 50,000 miles of *controlled test driving* (certification testing) for passenger cars, and 120,000 miles for light-duty trucks; however, VOC emission rates after 50,000 miles (for cars) and 120,000 miles (for trucks) of *actual* use by vehicle owners would likely exceed these standards. We assume that new standards go into effect in 1994 for both passenger cars and light-duty trucks.

percent by 2004 as new cars and trucks enter the Nation's vehicle fleet. Some of these and the other options can be implemented by the States in nonattainment areas alone, others are better suited to Federal implementation nationwide. Table 2-1 summarizes the options for implementing currently available control methods that may be most appropriately considered by Congress.

We can estimate the cost of applying all these controls in all nonattainment cities, bringing about half of the cities into compliance and substantially improving the air quality of the rest: between $4.3 and $7.2 billion per year in 1994 and between $6.6 and $10 billion annually by 2004, assuming the current state of technology. Because some controls would apply nationwide, rather than just in nonattainment areas, the *national* price tag would total about $8.8 to $13 billion in 2004.

Some of these controls simultaneously reduce other air pollutants in addition to VOCs. Enhanced motor vehicle inspection and maintenance programs also reduce nitrogen oxides and carbon monoxide. More stringent highway vehicle standards apply to nitrogen oxides, too. About $2.5 billion of the total cost in 2004 can be assigned to nitrogen oxide control, the benefit of which will be discussed later. About $1.5 billion per year can be assigned to control of carbon monoxide.

Depending on the method used, the cost of eliminating a ton of VOC emissions varies considerably. By far the cheapest is limiting fuel volatility, at about $120 to $750 per ton of VOC reduction; replacing gasoline with methanol or some other alternative fuel could be far more expensive than this, but the potential to lower fuel costs *in the long term* might eventually bring the "per ton" costs down to a range competitive with the other methods. The cheaper methods of reducing VOCs can provide reductions equal to about 25 to 30 percent of the 1985 emissions levels at total costs of $2 to $3 billion. As more reductions are required, though, more and more expensive methods must come into play, and the cost of additional reductions rises steeply.

Most of the control methods we analyzed cost between $1,000 and $5,000 per ton of VOC reductions obtained. We estimate that in 1994, if controls costing more than $5,000 per ton of reductions were excluded from consideration, total annual costs for the nonattainment areas would drop to about $2.7 to $5.1 billion per year, a drop of about 30 to 35 percent. There would be a corresponding loss in reductions of about 2 percent of 1985 emissions.

**Table 2-l—Options for Amending the Clean Air Act: Currently Available Control Methods**

**Federally implemented, nationwide control requirements:**
- Option 1: Limits on gasoline votality.
- Option 2: More stringent tailpipe exhaust standards for cars and trucks.
- Option 3: "Onboard" technology for cars and trucks to control refueling emissions.
- Option 4: Federal solvent regulations for example, for architectural coatings.

**Control requirements to be implemented by States in nonattainment areas:**
- Option 1: Lowered source-size cutoff for requiring "reasonably available control technology" (RACT).
- Option 2: Require EPA to define RACT for additional source categories.
- Option 3: More stringent requirements for motor vehicle inspection and maintenance programs.
- Option 4: Required use of alternative fuels by centrally owned fleets.
- Option 5: Transportation control measures.
- Option 6: Tax on gasoline.

**Managing growth:**
- Option 1: Lower the cutoff for new source control requirements
- Option 2: Eliminate "netting" out of new source control requirements.
- Option 3: Areawide emission ceilings.

SOURCE: Office of Technology Assessment, 1989.

All of the above costs could change if engineering advances reduce the costs of applying existing technologies, or if alternative methods and new technologies can achieve the same reductions using alternative, less costly means.

To summarize, if we are willing to use and pay for currently available technology, we can make significant advances over the next 5 to 10 years, achieving about two-thirds of the emissions reductions in nonattainment areas that we need. This should bring about half of the current nonattainment areas into compliance. But we cannot, by the year 2000, get the entire Nation to the goal that Congress established in 1970. In the worst areas, even the most costly and stringent of available measures will not lower emission levels sufficiently to meet the standard. Achieving that goal is a long-range project, well beyond the 5- and 10-year horizons of existing law. It will require both new technologies and lifestyle changes in the most affected communities, including changes in transportation, work, and housing patterns. In other, less polluted nonattainment areas, the standard can be met with less cost and disruption.

To meet the ozone standards in all cities, we must turn to new, nontraditional controls, with uncertain costs. With application of all of the traditional controls discussed above, by 1994, about 60 percent of the remaining manmade VOC emissions will come from small stationary sources that individually emit less than 25 tons per year. Over half of this latter category will come from surface coatings and other organic solvent evaporation.[9] In addition, between 25 and 30 percent of the remaining emissions will come from highway vehicles. Efforts to further reduce VOC emissions must focus on these sources. Table 2-2 summarizes the nontraditional VOC controls as well as other new options for controlling levels of urban ozone.

Regulators will face difficult problems in trying to control emissions from these sources. For example, to further reduce solvent emissions, regulators face the challenge of encouraging development of an enormous variety of new products, manufacturing processes, and control methods. One possible approach is applying existing controls to smaller sized commercial and industrial sources. This is no easy task for regulators, however, because hundreds of thousands of firms in nonattainment areas individually use small quantities of solvents. Another approach is to place limits on the permissible VOC content of certain products and processes; those that exceed the limit after a specified date would be banned from sale. These two strategies are variations on established 'engineering' techniques of regulating users. Also, market-based approaches could be used. For example, emission fees or marketable emission permits could be established to discourage use of products high in VOCs by making it more profitable to use substitutes. And in areas where consumer environmental interest and activism is strong, product labeling designed to identify "low emission" products could be a useful strategy.

### Table 2-2—Options for Amending the Clean Air Act: New Directions

**Controls on emissions of nitrogen oxides in nonattainment areas:**
- Option 1: Congressionally mandated $NO_x$ controls.
- Option 2: Presumptive $NO_x$ controls on stationary sources, with EPA authority to exempt areas under specified situations.
- Option 3: Requirements to analyze $NO_x$ controls under certain situations.

**Long-term control VOC strategies:**
- Option 1: Lowering emissions from solvents, either through traditional "engineering" approaches or through market-based mechanisms.
- Option 2: Transportation control measures.
- Option 3: Requirements for widespread use of alternative fuels in nonattainment areas that are far from meeting the standard.

**Controls in upwind areas:**
- Option 1: Enlarge nonattainment areas to include the entire extended metropolitan area.
- Option 2: Congressionally specified $NO_x$ controls in designated "transport regions" or nationwide.
- Option 3: Strengthen the interstate transport provisions of the Clean Air Act.
- Option 4: Provide EPA with clear authority to develop regional control strategies based on regional-scale modeling.

**Reducing ozone in attainment (rural) areas:**
- Option 1. Specify a deadline for EPA reconsideration of the ozone secondary standard and a schedule for options by the States.
- Option 2. Congressionally specified $NO_x$ controls.

**Research:**

Decision 1: What areas of research deserve increased funding?
- Improving the planning process, developing new control methods, and further evaluating the risks from ozone.

Decision 2: Who pays for the research?
- Option 1: General revenues.
- Option 2: User fees.

SOURCE: Office of Technology Assessment, 1989.

Cutting the use of motor vehicles, especially private cars, is another way to lower VOC emissions. Although technologically simple, it is politically difficult. The 1977 Amendments to the Clean Air Act required urban areas to implement transportation control measures (TCMs) necessary to meet ozone and carbon monoxide standards. Experience shows, though, that TCMs require considerable local initiative and political will because they aim to change the everyday habits and private decisions of hundreds of thousands of people. Involuntary TCMs have proven politically infeasible and voluntary programs difficult to sustain. Success requires long lead times, high priority in urban transportation and land-use planning, a high degree of public support and participation and, in some cases such as mass transit development, major capital expenditures. Possible tactics include requiring staggered work hours; encouraging carpools through inducements like priority parking places, dedicated highway lanes and reduced tolls; constructing attractive and economical mass transit systems; limiting available

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[9] Solvents are used in a wide variety of industrial, commercial, and home uses, from cleaning and decreasing heavy equipment to washing paintbrushes and removing spots from garments. They appear in thousands of commercial and consumer products such as personal-care products, adhesives, paints, and cleaners used daily throughout the country. They are used by manufacturers to paint or otherwise coat cars, appliances, furniture, and many other products in facilities that range from the huge to the tiny.

parking places; and encouraging employers to locate closer to residential areas, which would cut distances workers have to travel.

### *Controlling Nitrogen Oxides*

Historically, ozone control efforts have concentrated on VOC emission reductions both because methods were thought to be cheaper and more available and because in some cases reducing $NO_x$ may actually be counterproductive. As mentioned earlier, however, many areas of the country, especially rural areas but some cities as well, have mixtures of high atmospheric levels of VOCs in relation to $NO_x$ levels, creating conditions where ozone concentrations are limited by $NO_x$ rather than VOC. In these areas, successful reduction in ozone concentrations requires control of $NO_x$ emissions beyond current requirements.

Two types of sources, highway vehicles and electric utility boilers, account for two-thirds of $NO_x$ emissions. Highway vehicles contribute about a third of the national total, led by passenger cars with 17 percent and heavy-duty diesel trucks with 9 percent. In the southern California cities with design values above 0.26, highway vehicles account for about two-thirds of local $NO_x$ emissions; in most nonattainment cities, they contribute about 30 to 45 percent.

Under current regulations, total $NO_x$ emissions will increase steadily between 1985 and 2004, rising by about 5 percent by 1994 and by about 25 percent by 2004. (See figure 2-5.) As newer, cleaner cars replace older ones, highway emissions will decline until the mid- 1990s, only to rise again as miles traveled increase. Stationary sources, however, will increase their emissions steadily.

The impacts of controlling $NO_x$ emissions in nonattainment areas will vary from city to city. preliminary analyses indicate that in most southern cities (from Texas east), $NO_x$ reductions would help reduce ozone concentrations; in most isolated Midwestern cities, however, they might have the opposite effect. Recent results from EPA's Regional Oxidant Model (ROM) simulating ozone formation and transport throughout the Northeast over a 2-week period, indicate that in this region, results will be mixed. Overall, a one-third cut in $NO_x$ emissions on top of a 50-percent reduction in regionwide VOC emissions resulted in modest ozone benefits for most nonattainment cities, compared to a case where VOC emissions were controlled alone. A detailed examination, however, shows considerable variation among cities. Adding $NO_x$ controls *increased* population exposure to ozone at concentrations above the standard in some cities (e.g., Pittsburgh), decreased population exposure in some (e.g., Hartford), and resulted in negligible changes in others (e.g., New York). Further regional and city-by-city modeling is necessary to verify these conclusions.

$NO_x$ emissions affect more than just nonattainment area ozone concentrations, complicating the decision about whether to mandate controls. $NO_x$ emissions contribute to acid deposition and are a major determinant of elevated ozone concentrations in agricultural and forested regions. Though $NO_x$ reductions can have either a beneficial or detrimental effect on peak ozone concentrations in nonattainment areas,[10] they will most likely lower both acid deposition and regional ozone concentrations.

### *The Role of Alternative Fuels*

Recent promotion of alternative fuels has been based on their potential to reduce urban ozone, through reductions in "effective" VOC emissions, that is, reductions in actual VOC emissions by weight and/or reductions in the reactivity of the VOCs that are emitted. In addition, EPA and others view a major benefit of alternative fuels to be their elimination or reduction of toxic emissions of benzene, gasoline refueling vapors, 1,3-butadiene, and polycyclic organic matter.[11] All of the fuels examined in this report have, to differing degrees, some potential to yield reductions in effective emissions of VOCs if used appropriately, and all should reduce toxic emissions (except for aldehydes) as well. On the other hand, most of the fuels do *not* automatically yield reductions in $NO_x$, and some may add to $NO_x$ emissions under certain conditions. The emissions characteristics of the fuels are examined in the chapters that follow.

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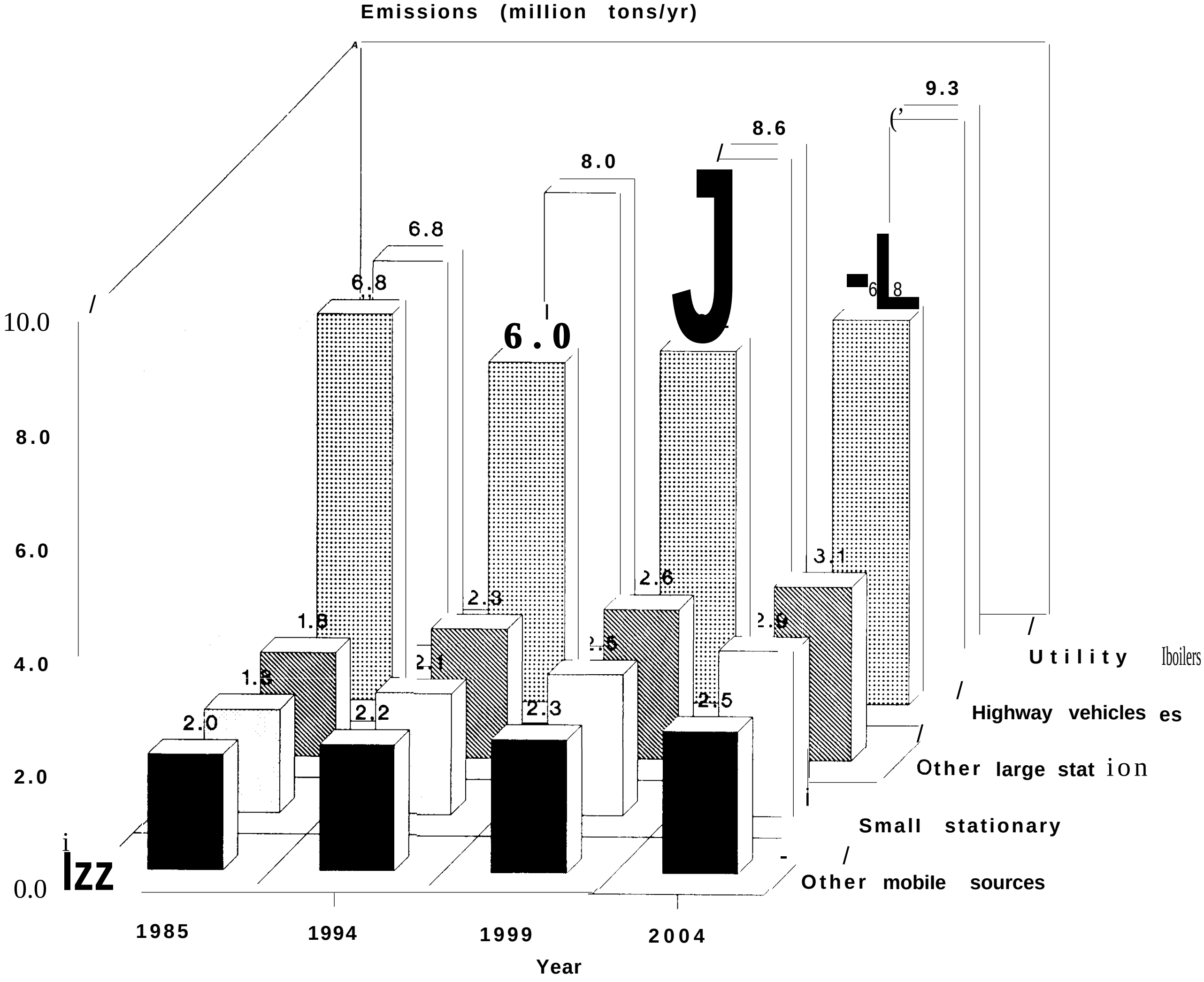
[10] The detrimental effect occurs at certain conditions with high atmospheric ratios of $NO_x$ to VOCs.

[11] Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Methanol as an Automotive Fuel*, Special Report, Office of Mobile Sources, September 1989.

**Figure 2-5-Summary of Estimated Nationwide Nitrogen Oxides ($NO_x$) Emissions by Source Category, by Year**



The numbers directly above the boxes are the total emissions within the source category. For example, emissions from highway vehicles in 1994 are 6.0 million tons per year, nationwide. Assumes no new laws or regulations.

SOURCE: Office of Technology Assessment, based on work by E.H. Pechan and Associates.

The complexity of the relationship between urban ozone, local VOC concentrations, local $NO_x$ concentrations, and long-range transport of ozone froms other areas implies that the use of alternative fuels will have substantially different impacts on urban ozone concentrations from city to city and area to area. In cities such as Los Angeles, with high $NO_x$ concentrations and ozone levels limited primarily by VOC levels, the reduction in effective VOC levels likely to accompany large-scale use of alternative fuels should yield a significant reduction in ozone levels.

In areas with high background levels of VOC and lower $NO_x$ levels, reductions in effective VOC emissions will be less successful in reducing ozone concentrations. In cities such as Houston and Chicago, and in most rural areas, the widespread use of alternative fuels is likely to have far less effect on ozone levels than similar use would have in VOC-limited areas. In fact, under some circumstances, attempts to gain maximum efficiency from vehicles using alcohol fuels or natural gas might interfere with stringent control of $NO_x$ emissions from these vehicles, and ozone reduction efforts actually might suffer slightly from use of such fuels.

# ENERGY SECURITY IN PERSPECTIVE

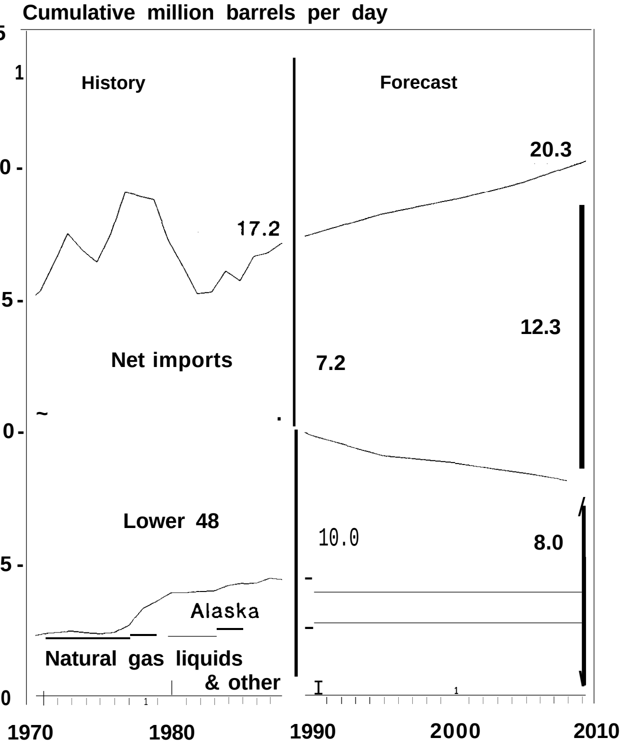
Many supporters of alternative fuels programs argue that introduction of such fuels to the highway fleet would provide substantial positive benefits to U.S. energy security, breaking oil's monopoly on highway transportation and providing an expandable new source of fuel in case of an oil supply disruption. Whether energy security benefits provide a powerful motive for government support of alternative fuels depends on the security risks actually faced by the United States, and the ability of alternative fuels to combat these risks.

## *Should Energy Security Be a Major Concern for U.S. Policymakers?*

To the extent that projections of continued reductions in domestic oil production and continued increases in U.S. and worldwide oil demand are correct-and we believe they *are* correct[12]--the United States has already resumed relatively high levels of oil imports from politically insecure sources (figure 2-6 shows the Energy Information Administration projections for future U.S. oil import levels). Congress clearly viewed the high levels of oil imports of the 1970s as a threat and responded with extensive legislation, including programs to promote synfuels development, tax incentives for energy conservation and alternative energy sources, an extensive energy R&D program, and the establishment of the Strategic Petroleum Reserve (SPR). In addition, Congress appropriated funds to establish military forces specifically designed to deal with threats far from established U.S. military bases, and, in particular, the Middle Eastern oilfields.

Industry supporters of congressional measures to fight increases in U.S. oil imports-such as opening environmentally sensitive areas to oil development, establishing tax incentives for increased domestic production, shifting from gasoline to nonpetroleum fuels, and so forth-have portrayed the potential increases in precisely the same manner, i.e., as a serious threat to the security and long-term economic interests of the United States. These supporters have pointed to the United States' large expenditures during the Iran/Iraq war in protecting U.S. flagged tankers in the Persian Gulf as one cost of growing U.S. oil import dependency. The fact that the United States is now deeply embroiled in a mideast conflict is another ''cost' that can be attributed to the United States' import dependency.

**Figure 2-6--EIA Projections of Petroleum Supply, Consumption, and Import Requirements to 2010, Base Case**



SOURCE: Energy Information Administration, *Annual Energy Outlook, 1990.*

It is important to recognize, however, that there are important differences between oil *dependency* and oil *vulnerability*. Dependence is simply the portion of total U.S. oil supplies that must be imported. Vulnerability, on the other hand, is not nearly so well-defined, but clearly is associated with the kind of damage that the United States would incur in the event of an oil shortage or price shock, and the risk of such an event.[13] The United States is vulnerable to economic and military disruptions

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[12] We do believe, however, that there are available policy measures that could slow, but not stop, the oil production decline and reverse the trend of increasing U.S. oil demand.

[13] See R.L. Bamberger and C.E. Behrens, "World Oil and the ANWR Potential,' Congressional Research Service Report 87-438 ENR, May 21, 1987, for more discussion on this theme. Also, OTA has evaluated the U.S. oil replacement capability in the event of an oil supply shortfall of indefinite duration; see U.S. Congress, Office of Technology Assessment, *U.S. Vulnerability to an Oil Import Curtailment; The Oil Replacement Capability, OTA-E-243* (Springfield, VA: National Technical Information Service, September 1984).

associated with Persian Gulf instability whether it is importing 30 percent of its oil or 70 percent, because any price increases attributable to that instability will affect all world oil supplies simultaneously and because U.S. agreements with its allies require sharing the effects of any widespread shortages.

This is not to say that the two import levels are identical in their implications. In particular, lower imports would reduce pressures on worldwide oil supply, lowering the probability of a disruption in supplies and/or a rapid price increase. Also, higher oil prices would likely damage a U.S. economy importing 70 percent of its oil more than the economy importing 30 percent, because more of the added energy expenditures would remain inside U.S. borders in the latter case. And if a percentage of U.S. highway travel relied on fuels whose prices were somewhat buffered from world oil prices-which is possible under certain circumstances[14]--the economic impact of an oil price shock would be still less.

Policymakers should also avoid attributing to U.S. oil vulnerability all costs of actions such as those of the United States in the Persian Gulf. Clearly, other geopolitical considerations were at stake here, including a desire to avoid allowing the Soviet Union the primary role in defending Kuwaiti shipping interests.

Furthermore, the United States' balance between domestic and imported energy is enviable compared to most of the developed world. Whereas U.S. oil imports for 1989 were about 46 percent of oil consumption (and less than 20 percent of total energy consumption), the European Organization for Economic Cooperation and Development (OECD) nations import about two-thirds of their oil, and Japan imports all of its oil and most of its energy. However, this difference might be interpreted in the opposite fashion: that it illustrates further the United States' dilemma, because of our close economic and military ties to the OECD nations.

Regardless of these arguments, what direct economic costs would the United States incur in the event of another oil price ''shock"? There appears to be a general consensus among U.S. energy policy analysts that the costs the United States actually incurred as a result of the earlier oil disruptions of 1973 and 1979 were very large, in terms of both inflationary impacts and the recessions that followed, and that these costs were caused by the rapid oil price rises that accompanied the disruptions. Although we are not prepared to dispute this point, we note that studies at Resources for the Future (RfF) of the relationship between the oil price shocks of the 1970s and the recessions that followed concluded that the shocks themselves had essentially no important adverse effects on output and employment in the United States and other industrial countries, and that the most likely cause of the worldwide recessions that followed the shocks were the very monetary and fiscal policies adopted to fight the effects of the shocks.[15] Because this alternative view of the danger of future price shocks leads to drastically different conclusions about energy policy than implied by the more conventional view, we hope that the RfF report will generate a vigorous, open-minded debate about the vulnerability of the U.S. economy.

If we, for prudence's sake, take the more conventional view of the danger of future oil price shocks, there is little doubt that an oil security threat to the United States still exists. The four basic elements to this threat-the dependence of the U.S. transportation sector on petroleum; the United States' limited potential to increase oil production; the preponderance of oil reserves in the Middle East/Persian Gulf (see figure 2-7); and the basic political instability and considerable hostility to the United States existing there-are as true today as they were in the early 1970s at the time of the Arab oil boycott.

In fact, in some ways these elements have grown more severe. For example, during the past 10 years, the transportation sector's share of total U.S. petroleum use has grown from 54 to 64 percent.[16] This is particularly important because the sector's prospects for fuel switching in an emergency are virtually zero. In addition, the boom and bust oil price cycle of the post-boycott period, and especially the price drop of 1985-86, may have created a wariness in the oil

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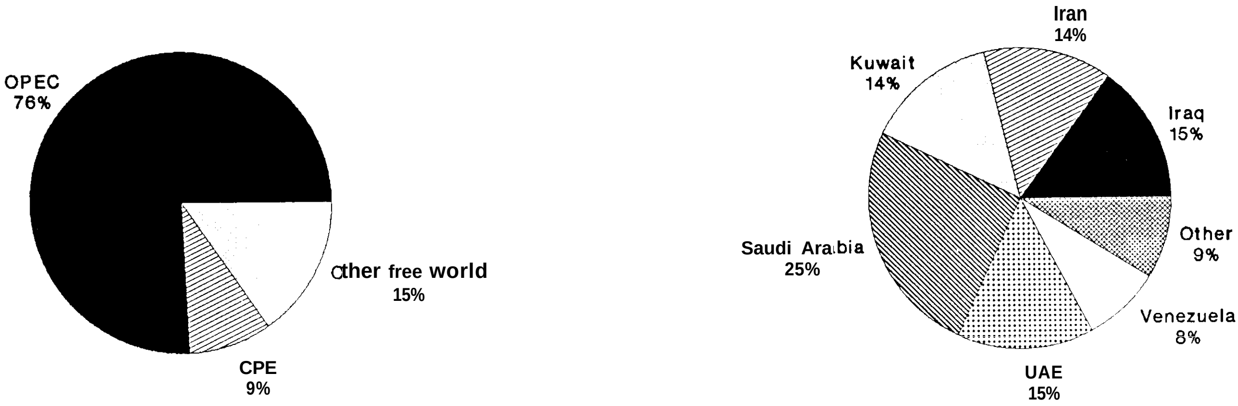
[14] For example, if feedstocks for producing the fuel had few other competitive uses, and if the vehicles using this fuel were dedicated rather tin flexible fuel.

[15] D.R. Bohi, *Energy Price Shocks and Macroeconomic Performance* (Washington, DC: Resources for the Future, 1989).

[16] Energy Information Administration, *Annual Energy Review 1985*, DOE/EIA-0384(85), May 1986, and *Annual Energy Outlook 1990*, DOE/EIA-0383(90), January 1990.

**Figure 2-7—Distribution of World Oil Reserves, 1988**



SOURCE: Arthur Anderson & Co./Cambridge Energy Research Associates.

industry that would substantially delay any major boost in drilling activity in response to another price surge. And, with the passage of time, the industry's infrastructure, including skilled labor, that would be needed for a drilling rebound is being eroded.[17]

Thus, if the United States is moving towards an energy situation similar to the one it faced in the 1970s, it may be facing severe economic risks. Therefore, an examination of any differences between the U.S. and world energy situation in the '70s and the situation today is an important element of evaluating U.S. vulnerability. There are several areas in which important differences may exist.[18]

### Petroleum Stocks

First, the United States now has a Strategic Petroleum Reserve containing in excess of 580 million barrels of crude oil,[19] the equivalent of about 81 days of oil imports at 1989 levels.[20] Similarly, Europe and Japan have also added to their strategic storage; the International Energy Agency countries, excluding the United States, had accumulated government owned and controlled stocks of about 360 million barrels by 1986.

Private stocks are also important. Currently, private stock levels in the United States are similar to levels in the early 1970s—a bit over 1 billion barrels.[21] Because stock levels were higher in the middle to late 1970s, averaging over 1.3 billion barrels in 1977, 10-year comparisons imply that private stocks have declined, nullifying some of the benefit of the SPR. Oil company analysts claim that the stock "decline" is due to the rationalizations of refining capacity and markets that have occurred during this time period, and that the minimum working stock needed in the supply system has declined. This explanation appears logical; however, a detailed analysis of private petroleum stock changes during the past decade and a half might be useful.

The value of substantial oil stockpiles in mediating the adverse effects of an oil disruption will be determined by the actual strategy used during a crisis. Ideally, stockholders will gradually release

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[17] For a discussion of the problems faced by the U.S. oil industry in the face of low world oil prices, and the effects on production, see U.S. Congress, Office of Technology Assessment. *U.S. Oil Production: The Effect of Low Oil Prices-Special Report, OTA-E-348* (Washington DC: U.S. Government Printing Office, September 1987).

[18] For a more detailed discussion of shifts in world oil markets, we recommend the General Accounting Office's report Energy *Security: An Overview of Changes in the World Oil Market,* August 1988.

[19] 580.2 million barrels as of January 1990. Energy Information Administration, *Weekly Petroleum Status Report,* data for week ended Jan. 26, 1990, DOE/EIA-0208(90-06).

[20] The average import rate for the first 11 months of 1989 was 7.16 mmbd. Ibid.

[21] Ibid.

their holdings to the market-ruse the stored oil as their supply source-in the aftermath of a decline in general oil availability. However, some stockholders may act to hold their stored oil-or even to increase the level of storage—if they perceive that oil prices will rise in the future. If hoarding is a widespread behavior, any adverse effects of an oil supply disruption will be magnified.

### Diversification of Oil Production

Second, world oil production has become substantially more diversified since the ‘70s, with OPEC’s share of the world oil export sales declining from 82 percent in 1979 to approximately 61 percent today,[22] and its share of total production dropping from 49 percent to 32 percent in the same time period.[23] For several years, at least, no single country or cohesive group of countries can control as large a share of the world market as was possible previously. Furthermore, there are new doubts about earlier assumptions that low oil prices would lead to contracting world oil supplies. In some of the higher cost oil producing areas, eased government taxes and royalties and extensive industry cost-cutting efforts have greatly reduced oil development costs, offsetting much of the damage to oilfield development prospects caused by falling prices.[24] Also, many analysts had previously assumed that the OPEC nations would not further expand their production capacities. It is now more widely recognized that the maintenance of excess capacity is important to retaining power within the OPEC organization, and OPEC nations may be likely to expand capacity rather than relinquish control. In addition, the cessation of hostilities between Iran and Iraq have given these countries the breathing space necessary to expand their production capabilities, with Iran having no outside source of income for rebuilding and thus turning to potential oil revenues as its primary source of capital, and both Iran and Iraq having added substantially to their reported proved reserves, which, combined, now rival those of Saudi Arabia.[25] If total OPEC production capacity grows rather than contracts, assumptions about the ‘ ‘using up” of OPEC’s excess production capacity and the return of market power to the Middle East—the centerpiece of “conventional wisdom’ warnings about future price increases—may be inaccurate.

Published projections of short-term trends in world crude production capacity support this view. The Energy Information Administration (EIA), for example, expects non-OPEC crude production to grow by about 600,000 barrels/day in 1990 and remain steady through the early 1990s despite slippage in the United States’ capacity.[26] EIA expects OPEC production capacity to grow by over 1 million barrels per day (mmbd) in 1990 and then continue to grow for the indefinite future.[27]

In counterpoint to this view is the expectation that the oil production rates of both the Soviet Union and Great Britain, in addition to the United States, will soon be in serious decline. In the early 1970s, prospects for these important regions were positive, in contrast. In addition, the number of areas that remain unexplored and unexploited is much lower now than it was in the early 1970s. This is a critical factor, because it implies that a future price increase would be less likely to stimulate new supplies than previously.

### Reversibility of Demand

Third, there have been changes—both positive and negative—in the ability of the economies of both the United States and the remainder of the Free World to reverse a portion of any increase in oil consumption. On the negative side, as noted previously, the U.S. transportation sector’s share of total oil use increased from 54 to 64 percent over the past 10 years. Because transportation fuel use is essentially locked into petroleum for all but the long term, this shift has hurt the economy’s ability to switch from oil. On the positive side, in the U.S. industrial

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[22] The Middle East’s share of world trade was 58 and 42 percent, respectively.

[23] Arthur Andersen & Co. and Cambridge Energy Research Associates, *World Oil Trends, 1988-1989 Edition*, table 16.

[24] Areas where oilfield development originally thought to require $25/bbl oil has continued at prices well below $20/bbl include several North Sea fields and a number of development projects on the North Slope of Alaska.

[25] According t. *World Oil Trends, 1989-1990 Edition* , op. cit., footnote 23, table 21, Iran and Iraq essentially doubled their reported oil reserves between 1987 and 1988, from a combined 95.9 billion barrels to 192.9 billion barrels. By comparison, Saudi Arabia had 169.6 billion barrels of reserves in 1988, though it revised its estimated reserves upwards in January 1989, to 255.0 billion barrels (Energy Information Administration *International Energy Annual 1988, DOE/EIA-0219(88),* November 1989).

[26] Energy Information Administration, *International Energy Outlook 1990*, DOE/EIA-0484(90), March 1990, table A2.

[27] Ibid., table B3.

sector, shifts to oil for a boiler fuel can be readily reversed with a shift back to coal or natural gas. During the past decade, industry has made a vigorous effort to insure that its boiler capacity has rapid fuel-switching capability. Similarly, in the electric utility sector, a portion of increased oil use has involved the use of existing oil-fired generating capacity—removed from baseload service when oil prices rose in the 1970s—in place of coal, gas, or even nuclear plants. As long as the industry retains excess generating capacity, this use can also be reversed. The steady decline of the utility sector's excess capacity is diminishing the potential for reversal, however.

Another threat to reversibility is the potential for inadequate supplies of natural gas resulting from the same drilling slowdown acting to reduce oil production. A gas supply shortage is a realistic possibility only in the United States, as world gas reserves have expanded substantially and, generally, adequate supply seems assured. There is considerable controversy about U.S. gas supply adequacy for the future. Some analysts are projecting an imminent market tightening if gas prices stay low, followed by supply problems as domestic production capability continues to decline. Others claim, however, that significant gas shortages (excepting short-term seasonal shortages) are extremely unlikely, because additional large volumes of gas can be made available rapidly if markets tighten, by increasing import levels and by developing reserves now kept out of the market by low demand and inadequate price. Furthermore, even at reduced drilling rates, trends in gas reserve additions have rebounded this year, and continued progress in recovery of unconventional gas (such as coal-bed methane) is encouraging to long-term resource availability. OTA agrees that prospects for ample natural gas supplies, although still somewhat uncertain, have improved greatly during the past decade.

### Experience

Fourth, the United States and its allies have undergone two major price shocks in the recent past, and this additional experience, as well as a series of international agreements on oil sharing, may assist them in a future supply crisis. Many oil experts are skeptical about the usefulness of these agreements, however. A special concern is the difficulty of defining the market conditions that constitute an actionable disruption; in particular, the relationship between the magnitude of supply reductions and the economic impact of those reductions has been difficult to specify.[28]

### Balance of Trade

Fifth, in the 1970s some of the economic effects of oil imports, specifically those associated with the U.S. balance of trade, were offset by large trade surpluses in other sectors. The current absence of large balancing trade surpluses-in 1989, the United States ran a merchandise trade of $111 billion and paid $44.7 billion for its oil imports[29]--may change the relative importance of oil imports to the U.S. economy and may weaken the ability of the economy to absorb the effects of a large jump in the dollar value of imports, which would occur if oil prices were to rise rapidly.

### Price Decontrol

Sixth, U.S. oil prices are no longer controlled as they were during the 1970s. For years following increases in world oil prices, the price of oil products were held artificially low in the U.S. market. The result was that the potential market responses—increased production activity and decreased oil demand—were stifled. In the event of a new increase in world oil price, the market forces that act to reduce demand and increase supply will be felt in full (assuming price controls are not resumed). Similarly, the wide recognition that the Federal Government's attempts to allocate gasoline during the earlier crises were counterproductive may help prevent misguided regulatory distortions in future crises.

### Market Shifts

Seventh, most of the world's oil trade now operates on the spot market, in contrast to the long-term contracts of the 1970s (a spot market is a short-term market where prospective buyers can obtain bids for immediate shipment and timely delivery of crude and petroleum products). Coupled with an active futures market, this new oil trading situation makes single country embargoes, which could never be airtight even in the past, still less of a threat. Also, because world refinery capacity is

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[28] See D.R. Bohi, *Evolution of the Oil Market and Energy Security Policy* (Washington, DC: Resources for the Future, 1986).

[29] *Economic Report of the President* (Washington DC: U.S. Government Printing Off@ February 1990).

considerably more flexible in terms of the crudes that can be expected, the ability of countries to switch oil suppliers is greater than during the 1970s.[30]

### Economic Limits on Producers

Eighth, the ambitious and very expensive internal development programs of the OPEC nations and the financial difficulties most have encountered in the 1980s reduce their ability to absorb a large drop in their oil revenues, making oil boycotts less likely. The OPEC countries' current account balances, which reached a high of nearly $100 billion in 1980, have been negative between 1982-87.[31] Furthermore, during the past decade and a half, several OPEC countries have invested heavily in the economies of Western oil-importing nations, and particularly in their oil-refining and marketing sectors. For example, Kuwait has established an extensive gasoline marketing network in Europe under the trade name Q8, and Saudi Arabia has large investments in the U.S. refining sector. An oil embargo could severely damage these investments.

### Flexibility of Oil Transportation

Ninth, the Strait of Hormuz has become less important as a critical potential bottleneck of Persian Gulf oil supply. The Iran Iraq war and its effects on tanker traffic in the Persian Gulf stimulated the diversification of oil transport routes out of the Gulf nations. In particular, pipeline capacity capable of taking Persian Gulf oil to ports outside of the Gulf grew from less than 1 mmbd in the late 1970s to between 4.5 and 4.8 mmbd in 1987.[32] Although pipelines are vulnerable to sabotage or direct attack, damage to most pipeline segments can generally be quickly repaired; the more difficult to repair pumping stations, being limited in number, are easier to defend. Also, most of the pipeline lengths are located in Saudi Arabia and Turkey. Conventional, direct attacks within these countries would encounter serious problems, although such attacks certainly cannot be ruled out.[33]

### Changing Military Power Balance

Tenth, unsettling changes in military power have occurred in the Middle East since the early 1970s. Iraq, for example, has assembled military forces large and effective enough to make outside intervention extremely costly for Western forces, should such intervention become desirable. The rise in power of the three States of Iran, Iraq, and Syria has been disproportionate to that of the other Middle Eastern OPEC nations. Furthermore, these States, and in particular Iraq, now have access to chemical arms and to long distance capability to deliver munitions by missile, putting Israeli and Egyptian civilian populations at risk. Consequently, the threat to the weaker OPEC nations of blackmail or invasion by Iraq or others has grown since the 1970s. At the time of final editing of this report, Iraq had just invaded Kuwait, with unpredictable consequences for oil supply and prices.

### Natural Gas

Eleventh, intensive exploration programs during the last decade and a half have uncovered very large resources of natural gas, spread in a somewhat more diversified reamer than oil resources. This gas provides an alternative fuel to oil used in boilers in many areas, and provides a potential longer term source of fuel suitable for transportation use, as methanol, synthetic gasoline, or LNG/CNG. Although the current world gas trade is small, and local use requires capital-intensive pipeline systems, gas use is growing and its potential provides a bargaining chip in dealings between oil users and suppliers.

This variety of changes in world oil markets can be summarized as a general shift to more flexible and responsive markets, with closer economic ties between oil producers and users, leading to lower risks of market disruptions and improved capability for effective *short-term* responses to such disruptions. There is a major counterpoint to this general improvement in worldwide and U.S. oil security: the likely reduction in long-term oil production responses to significant market disruptions. In particu-

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[30] W.A. Johnson, The JOFFREE Corp., "Oil: A Future Crisis in the Making?" testimony at hearings before the House Subcommittee on Energy and Power, Committee on Energy and Commerce, Mar. 23, 1987.

[31] Arthur Andersen & Co. and Cambridge Energy Research Associates, op. cit., footnote 23.

[32] R.L. Bamberger and C.R. Mark, "Disruption of Oil Supply from the Persian Gulf: Near-Term U.S. Vulnerability (Winter 1987/88 ),' Congressional Research Service Report 87-863 ENR, Nov. 1, 1987. Although an additional 2.4 to 2.7 mmbd of capacity are theoretically available in nonoperational lines, it is unlikely that much of this capacity can be restored.

[33] Ibid.

lar, prospects for finding large new sources of oil supply appear to be considerably poorer than in the 1970s. In the United States, prospects for an oil production response to a price shock seem poorer than during the 1970s simply because many of the opportunities have been pursued during the interim. Although there have been improvements in oilfield technology and methods for enhanced oil recovery during the past decade and a half, few would argue that these improvements will fully compensate for the intensive oilfield development that has occurred during the same period.

In OTA's view, the overall effect of this complex series of changes and adjustments since the early 1970s has been a net improvement in U.S. and world energy security, at least for the short term. We believe that a substantial disruption of oil markets is now less likely than it was then, and that the industrial nations are now better equipped to handle a disruption were it to occur, especially over the short-term. Further, the recent political changes in the Soviet Union and its Eastern Bloc neighbors may redefine basic perceptions about the nature of U.S. national security problems. Nevertheless, it remains true now, as it did then, that the lion's share of the world's oil reserves lies in the Persian Gulf nations, that these nations have most of the world's excess oil production capacity, and that they remain politically shaky. As long as this is true, and as long as a sharp price shock would be disruptive to the U.S. economy—which it would, though the magnitude of the disruption is in dispute--policymakers must still count effects on energy security as an important factor in judging proposed energy policy measures. However, the relegation of energy security from the ‘‘number one energy issue’ status that it held in the 1970s, to the somewhat lower status that it has today, seems to be a reasonable response to both a reduced security risk and an elevation of concern about environmental issues.

### *Energy Security Effects of Alternative Fuels*

Development of alternative fueled systems—vehicles, supply sources, and distribution networks—is viewed by supporters as both a means to reduce dependence on oil, lowering the economic and national security impact of a disruption and/or price rise, and as leverage against oil suppliers-' ‘raise the price too high, or disrupt supply, and we will rapidly expand our use of competing fuels. ' OTA concludes that the use of alternative fuels does offer *the potential* to significantly enhance U.S. energy security, but the effect depends greatly on the fuel chosen, the scale of the program, and the specific circumstances of the supply and vehicle system used.

At a large enough scale, an alternative fuels program could reduce the United States' overall demand for oil and its level of oil import dependence. If the price of the fuels were not tied too tightly to world oil prices—a possibility under limited circumstances-use of alternatives could reduce the primary economic impact of an oil disruption, since any price rise associated with such a disruption would apply to a lower volume of oil. Even if alternative fuel prices *were* tied to world oil prices, a large-scale *worldwide* program would reduce pressures on world oil supplies, reduce OPEC market dominance, and lessen the potential for future market disruptions. Also, the threat of rapid expansion of the program would be far more credible after the basic distribution infrastructure was widely emplaced and economies of scale achieved.

On the other hand, unless it were simply “phase 1“ of a larger program, a small-scale program—either a true experimental program, or one aimed only at ozone reduction in a limited number of cities—would likely have very small security benefits, though at moderate cost and risk. A limited program can serve as a laboratory to develop and free-tune technologies and marketing strategies, putting the United States a few years up the learning curve if it had to respond to a long-term crisis in oil supply. Given the slow turnover of the fleet and the significant infrastructure requirements for emplacing an alternative fuels system, however, this benefit, though useful, probably should be considered minor. A small-scale program could also serve as a symbol to OPEC, a reminder that an attempt to use their oil power as a weapon could backfire. However, current OPEC governments appear quite aware of the availability of longer term substitutes for oil, and future crises seem more likely to be created by radical governments that will not be readily swayed by considerations such as these. Finally, a small-scale program can serve as a first phase of a larger program, designed to work the “bugs” out of the technology and system design and to avoid large, expensive mistakes. In this role, a small program can have substantial advantages, though these must be traded off against the delay in emplacing a system large enough to affect energy security.

The efficacy of an alternative fuel program in providing security benefits, especially in the short term, will depend on whether the vehicles are dedicated to a single fuel or else are able to use multiple fuels. If the program relied on flexibly fueled vehicles (FFVs), this would allow the United States to play off the suppliers of oil against suppliers of alternative fuels, and would avoid the potential problem—inherent in a strategy favoring dedicated vehicles-of giving up one security problem (OPEC instability) for another (instability in whichever group of countries becomes our supplier of alternative fuels). However, a fleet of flexibly fueled vehicles attains important leverage against energy blackmail only if the supply and delivery infrastructure is available to allow them to be fueled exclusively with the alternative fuel, if this becomes necessary. FFVs don’t *require* widespread availability of an alternative fuel supply network to be practical during normal times, so adoption of an FFV-based strategy will not guarantee full infrastructure development unless there are regulatory requirements for such development. In fact, because dedicated vehicles are likely to have performance and emissions advantages over FFVs, policymakers may view FFVs as only a stopgap measure on the way to a dedicated fleet.

Having a fuel be domestically available clearly is a net benefit for short-term energy security considerations,[34] but the necessity of importing the fuel does not negate all security benefits from an alternative fuel. If the potential supply sources are different from the primary suppliers of crude oil, or even if the supply markets are simply more open to competitive pressures, a turn to alternative fuels would have advantages to national security. As discussed in the chapters on individual fuels, there are wide differences in the likely supply sources for the various fuels.

There are also clear security differences between fuels that are “unique”—not used elsewhere in the economy—and those that are widely used. There are substantial energy security advantages in having vehicles powered by fuels-such as natural gas and electricity-that also power other important segments of the U.S. economy. In the event of a crisis, emergency measures to reduce demand for these energy sources throughout the economy might free up fuel supplies for the transportation sector. With the greatly reduced use of oil in the nontransportation segments of the economy, and with much of the remaining use in the form of residual oil-not easily transformed into transportation fuels (exception: production of electricity for electric vehicles or electrified mass transit systems)---there are few remaining opportunities to free up oil for transportation.

As a final point, we have assumed in our discussions that the marginal barrel of oil eliminated by an equivalent volume of alternative fuel used in the United States will be an imported barrel. This view has been disputed by some analysts,[35] who claim that alternative fuels will eliminate the higher cost supplies, e.g., domestic oil production. We note that it is the high *price* of imported oil, not its low cost, that is relevant to which barrel is eliminated. However, if a large alternative fuel program results in keeping world oil prices (and thus domestic oil prices) well below what they would have been without such a program, domestic oil production could decrease. This decrease would certainly not be on a one-to-one basis with alternative fuel use, but it would temper the energy security advantage of a given volume of fuel substitution. We note that this theoretical “disadvantage” of an alternative fuels program applies equally well to any measures, including energy conservation, that would reduce pressure on world oil supplies. We do not believe that this potential is a serious concern.

## THE GREENHOUSE EFFECT IN PERSPECTIVE

### *Introduction*

The “greenhouse” effect—a warming of the Earth and the atmosphere—is the result of certain atmospheric gases absorbing the thermal radiation given off by Earth’s surface, and trapping some of

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[34] Many in the environmental community have raised questions about the wisdom of ‘draining America first,“ which makes the issue of the long-term benefits and costs of increasing domestic oil and gas production somewhat more contentious. Discussions of this issue can quickly degenerate into ideological argument, and we have not presented an analysis and discussion here.

[35] For example, see M.A. DeLuchi, R.A. Johnston, and D. Sperling, “Methanol vs. Natural Gas Vehicles: A Comparison of Resource Supply, Performance, Emissions, Fuel Storage, Safety, Costs, and Transitions,” Society of Automotive Engineers Technical Paper Series, #881656, 1988.

this radiation in the atmosphere.[36] The Earth's natural greenhouse effect is due primarily to water vapor, clouds, and carbon dioxide ($CO_2$), with small contributions from other trace gases that have natural sources, such as methane ($CH_4$) and nitrous oxide ($N_2O$). Without its natural atmospheric heat trap, Earth's surface temperatures would be about 60 OF cooler than at preSent.[37]

The "heat trapping" property of greenhouse gases is essentially undisputed. What *is in* question is how the Earth's climate will respond to the accumulation of man-made emissions, and the resulting increase in heat trapping, over the last century and into the next. Carbon dioxide, chlorofluorocarbons, methane, and nitrous oxide are known to be increasing annually in the atmosphere due to man's activities (see box 2-A). The effect of the increases in concentrations of carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), chlorofluorocarbons (CFCs), and other gases since the late 1800s is extra heat trapping equivalent to about a 1.4 'F (0.8 'C) equilibrium warming in global average surface temperatures.[38]

This "direct" heat trapping effect, or "radiative forcing' '[39] as it is often called, is the amount of warming expected to eventually occur at the Earth's surface if potential climate feedbacks—processes that amplify or diminish warming—are ignored. However, scientists expect that some climate feedbacks will operate; thus, **actual warming** cannot be neatly predicted.

In addition, while the human-induced component of the greenhouse effect increases in magnitude, other causes of climate changes remain important and make predicting future climate difficult. These include changes in the amount of energy emitted by the sun, changes in the atmospheric composition due to volcanic eruptions and man-made aerosols, incidences of El Ninos, and other unpredictable events.

Some regions of the globe will experience more than the average warming, and some regions less warming or even cooling, due to shifts in atmospheric and oceanic circulation patterns. Changes expected to accompany warming include arise in sea level and a more vigorous hydrological cycle, i.e., more precipitation and evaporation. Other predicted but less certain consequences include more drought in some regions; and more frequent and intense tropical storms. Scientists remain uncertain about the details of these impacts: what their magnitude will be; how fast they will develop; and which regions of the world they will affect.

### Key Uncertainties

Most scientists agree that ***some warming will occur in the*** next century; instead, the controversy involves the geographical distribution of temperature changes—"where?"; the timing and rate of such changes—' 'when?' and the magnitude of the changes—' 'how much?

The frost issue—"where? ''—is likely to remain unresolved for many years. Scientists have significantly less confidence in temperature change predictions for specific regions than for global averages, beyond the general expectation that the greatest warming will occur at high latitudes in the Northern Hemisphere. Climate models are not expected to provide reliable guidance on regional variations in temperature and rainfall patterns due to increasing greenhouse gases for some time-research on the order of a decade may be needed before such refinement will be possible.

The second question-' when? '-depends a great deal on the role the ocean plays in temperature

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[36] Greenhouse gases emit as well as absorb thermal radiation, but the net effect is absorption, because greenhouse gases absorb relatively intense radiation from the warmer Earth, and emit relatively weakly, at cooler atmospheric temperatures. Thermal radiation declines as the temperature of the emitting object declines.

[37] Differences in the concentrations of $C0_2$in the atmospheres of Earth, Mars, and Venus help to explain the contrast in the average surface temperatures of the three planets-from roughly -600 F (–500 C) on Mars to 750° F (400° C) on Venus, compared to a global, annual average of about 600 F (15° C) on Earth.

[38] V. Ramanathan, R.J. Cicerone, H.B. Singh, and J.T. Kiehl, "Trace Gas Trends and Their Potential Role in Climate Change," *J. Geophysical Research* vol. 90, pp. 5547-5566, 1985; and R.E. Cicerone, "Future Global Warming from Atmospheric Trace Gases," *Nature* vol. 319, pp. 109-115, 1986.

[39] Radiative forcing or heat trapping is calculated with models of the energy balance of the Earth/atmosphere system. These models calculate surface temperature adjustments to increased greenhouse gas concentrations from information about the radiative absorption characteristics of the gas molecules, and globally averaged profiles of gas concentration versus height in the atmosphere. The models also require information about preexisting conditions, such as atmospheric temperature profiles; the amount of solar energy entering the atmosphere and the amount reflected from Earth's surface and from atmospheric aerosols and gases; and the rate at which heat is redistributed through mechanical mixing processes.

## Box 2-A-Greenhouse Gases

Carbon dioxide ($CO_2$) concentrations in the atmosphere are estimated to have increased by about 25 percent since the mid-1800s, from around 280parts per million then to about 350 parts Per million now. Carbon dioxide concentrations have been measured at Mauna Loa since 1958; the record shows a steady increase from year-to-year superimposed on a clear seasonal cycle. The seasonal variation reflects winter-to-summer changes in photosynthesis ($C0_2$ storage) and respiration ($C0_2$ release) in live plants. Most of the increase is attributable to growth in fossil fuel use in the 20th century[1] unless current trends change, $C0_2$ concentrations in 2030 are typically projected to be about 450 ppm, about 60 percent higher than preindustrial levels.[2] Carbon dioxide concentrations in air bubbles trapped in Antarctic ice indicate that present $CO_2$ levels are already higher than at arty time in the past 160,000 years. Over that period, $C0_2$ concentrations were correlated with temperature, and ranged from roughly 200 parts per million during glacial episodes to *270* parts per million during interglacial periods.[3] Currently, $CO_2$ contributes about 50 percent of the greenhouse effect.

Methane ($CH_4$) measurements made since 1978 indicate a steady rise of about 1 percent per year, from about 1.5 ppm in 1978 to about 1.7 ppm in 1987.[4] Primarily from its domestic animals, natural gas and coal production, and landfills, the United States apparently contributes about 10 percent of the methane emissions due to human activity? Per molecule, methane is about 25 times more effective in trapping heat than $C0_2$.[6] Currently, $CH_4$ contributes about 18 percent of the greenhouse effect.

Nitrous oxide ($N_20$) concentrations apparently began to rise rapidly in the 1940s, and increased about 0.2 to 0.3 percent per year during the mid-1980s. Sources of $N_20$ are primarily associated with soil nitrification and denitrification. $N_20$ is also produced during biomass and fossil fuel combustion; the magnitude of emissions from fossil fuel combustion is currently highly uncertain due to errors in sampling for $N_20$.[7] Per molecule, the warming effect of nitrous oxide is about 200 times greater than that of $C0_2$.[8] Currently, $N_20$ contributes about 6 percent of the greenhouse effect.

Concentrations of the most widely used chlorofluorocarbons (CFCs), CFC-1 1 and CFC-12, were 0.2 and 0.4 parts per trillion, respectively, in 1986, increasing at a rate of about 4 percent per year.[9] Increases in CFC concentrations are unambiguously due to human activity, as they are synthetic chemicals that do not occur naturally. U.S. Environmental Protection Agency[10] projects that the rate of increase will be curtailed by the Montreal Protocol on Substances that Deplete the Ozone Layer, which was signed in September 1987; but that nevertheless, by 2030, concentrations of CFCs 11 and 12 will increase to 0.5 and 1.0 parts per billion, respectively. Use of CFC 11 in this country is dominated by production of synthetic foams for cushioning and insulation. The largest use of CFC 12 is in motor vehicle air conditioners. Outside of the United States, both CFCs 11 and 12 are commonly used in aerosol sprays. The warming effect of CFCs is on the order of 10,000 times greater, per molecule, than that of $C0_2$.[11] Currently, CFCs contribute about 15 percent of the greenhouse effect.

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[1] C.D. Keeling, "Industrial Production of Carbon Dioxide From Fossil Fuels and Limestone," *Tellus*, vol. 28, pp. 174-198, 1973; R.M. Rotty and C.D. Masters, "CarbonDioxide From Fossil Fuel Combustion: Trends, Resources, and Technological Implications," in J.R. Trabalka (cd.), *Atmospheric Carbon Dioxide and the Global Carbon Cycle,* DOE/ER-0239 (Washington, DC: U.S. Department of Energy, December 1985); and A.M. Solomon, J.R. Trabalka, D.E. Reichle, and L.D. Voorhees, "The Global Cycle of Carbon," in J.R. Trabalka (cd.), *Atmospheric Carbon Dioxide and the Global Carbon Cycle*, U.S. Department of Energy, DOE/ER-0239, Washington DC, December 1985.

[2] U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, *Policy Optionsfor Stabilizing Global Climate*, draft report to Congress, D.A. Lashof and D.A. Tirpak (eds.) (Washington DC: February 1989); V. Ramanathan, L.B. Callis, Jr., R.D. Cess, J.E. Hansen, I.S.A. Isaksen, W.R. Kuhn, A. Lacis, F.M. Luther, J.D. Mahlman, R.A. Reck, and M.E. Schlesinger, "Trace Gas Effects on Climate," in *Atmospheric Ozone 1985*, Global Ozone Research and Monitoring Project Report No, 16, World Meteorological Organization, National Aeronautics and Space Administration Washington DC, 1985; and J. Hansen, I. Fung, A. Lacis, S. Lebedeff, D. Rind, R. Ruedy, G. Russell, and P. Stone, "Global Climate changes as Forecast by the Goddard Institute for Space Studies Three-Dimensional Model," *Journal of Geophysical Research,* vol. 93, pp. 9341-9364, 1988.

[3] J.M. Barnola, D. Raynaud, Y.S. Korotkevich, and C. Lorius, "Vostok Ice Core Provides 160,000-year Record of Atmospheric $CO_2$," *Nature*, vol. 329, pp. 408414.

[4] See D.R. Blake and S.F. Rowland, "Continuing Worldwide Increase in Tropospheric Methane, 1978 to 1987," *science*, vol. 239, pp. 1129-1131, 1988.

[5] U.S. Environmental Protection Agency, 1989, op. cit., footnote 2.

[6] Ibid.

[7] L.J. Muzio and J.C. Kramlich, "An Artifact in the Measurement of $N_2O$ From Combustion Sources," *Geophysical Research Letters*, vol. 15, pp. 1369-1372, 1988.

[8] U.S. Environmental Protection Agency, 1989, op. cit., footnote 2.

[9] Ibid.

[10] Ibid.

[11] V. Ramanathan et al., 1985, op. cit., footnote 2.

SOURCE: Office of Technology Assessment, 1990.

regulation, which is only partially understood and incorporated into current models. Oceans play important roles in the climatic response to changed temperatures because they emit and absorb both heat and $CO_2$ and because changing ocean circulation can change the distribution of energy throughout the entire climate system. The upper ocean (50 to 100 m) appears to respond relatively rapidly to temperature changes; if interactions with the deep ocean are important, time lags up to 100 years for equilibration with the atmosphere may be required. Such lags would greatly slow down the "appearance' of global warming. On the other hand, as oceans warm, they may absorb a smaller fraction of $CO_2$ put into the atmosphere each year, which would accelerate the warming.[40]

The third issue—''how much?' '-depends on the role of climate feedbacks. Feedbacks can either enhance (positive feedback) or diminish (negative feedback) the warming effect expected from simply increasing concentrations of the greenhouse gases. Physical feedback mechanisms include water vapor, snow and ice, and clouds. When the climate warms, the atmosphere can hold more water vapor. This enhances warming because water vapor itself is a greenhouse gas. Despite some recent controversy[41], most scientists believe the positive effect of water vapor on temperature dominates any regional negative feedbacks from water vapor (e.g., increased cloud cover near the equator).

When climate warms, snow and ice will melt, reducing the reflectivity of the Earth and increasing its absorbance of heat. The insulating property of the ice is also lost, allowing a transfer of heat to the atmosphere from the ocean. Thus, in general, snow and ice feedbacks also appear to increase warming. However, nine new studies presented at the American Geophysical Union's meeting last fall suggest the south polar ice sheet may actually get bigger due to a warmer atmosphere carrying more moisture and depositing more snow on Antarctica. This outcome has reduced estimates of projected sea level rise to about 14 inches (ranging from a drop in 2 inches to arise of *30* inches) from the earlier (1987) National Academy of Sciences estimate of *20* to *59* inches.[42] The projected net change in sea level is still positive because the melting of Greenland's ice sheet and expansion of ocean water as it warms up will outweigh the effect of the enlargement of the Antarctic ice cap.

Important uncertainties about cloud formation limit our understanding of how climate will respond to greenhouse forcing. Clouds play a dual role in Earth's energy balance: depending on their shape, altitude, and location, their dominant effect can either be to reflect solar radiation or absorb thermal radiation. Satellite data have recently been used to demonstrate that the dominant effect of clouds at present is to reflect solar radiation and hence help cool the earth.[43] However, as conditions change, whether cloud feedbacks will amplify or reduce greenhouse warming depends on whether the cooling effects of clouds increase compared to their warming effects, or vice versa. If all types of clouds simply increase in area, they will reflect more sunlight back into space and cool the earth. If, as some new research suggests, taller narrower clouds form, or thin cirrus clouds form, they will actually exacerbate the warming effect. Sensitivity analyses conducted recently on the current models suggest they are extremely sensitive to assumptions about cloud cover. A comparison of 14 General Circulation Models concluded that clouds can have either a strongly positive or strongly negative feedback effect on global warming.[44] They can halve the expected warmin[45] or double it.[46]

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[40] D. Lashof, "The Dynamic Greenhouse: Feedback Processes that May Influence Future Concentrations of Greenhouse Gases and Climate,' *Climatic Change, in* press, 1989.

[41] R. Lindzen, unpublished paper, Massachusetts Institute Of Technology, 1990.

[42] National Academy of Sciences, *Responding t. Changes in Sea Level:* Engineering *Implications* (Washington, DC: National Academy of Sciences, 1987),

[43] V. Ramanathan, R.D. Cess, E.F. Harrison, P. Minnis, B.R. Barkstrom, E. Ahmad, and D. Hartmann, "Cloud-Radiative Forcing and Climate: Results From the Earth Radiation Budget Experiment" *Science,* vol. **243,** pp. 57-63, 1989.

[44] R. Cess, State University of New York, Stony Brook, as quoted by Richard Kerr, *Science,* vol. 243, pp. 28-29, 1989.

[45] J.F.B. Mitchell, *The Equilibrium Response to Doubling $CO_2$ in Greenhouse-Gas-Induced Climatic Change: A Critical Appraisal of Simulations and Observations,* Michael E. Schlesinger (cd.), (Elsevier) in press.

[46] V. Ramanathan, ' 'The Greenhouse Theory of Climate Change: A Test By an Inadvertent Global Experiment, ' *Science,* vo1. 240, pp. 293-299, 1988.

### *Benchmark Warming—The Effect of Doubled $CO_2$*

Predictions of future warming due to greenhouse gases are highly uncertain, largely because of the uncertainties inherent in both the climate models themselves and in the forces driving climate to change. Future emissions will be tied to future population and economic growth, technological developments, and government policies, all of which are notoriously difficult to project. In order to avoid the pitfalls and complexity of trying to estimate future emissions, and to provide a common basis for comparing different models or assumptions, standard practice on the part of climate modelers has been to perform sensitivity analyses. Typically, this entails examining equilibrium climates associated with preindustrial $C0_2$ levels, and then comparing them to equilibrium climates associated with doubled atmospheric $C0_2$ concentrations. Although such calculations are unrealistic in that they *instantaneously* double $CO_2$ concentrations, rather than increasing them gradually over time, they provide a useful "benchmark" of the sensitivity of climate to rising greenhouse gas concentrations.

Reviews of doubled-$C0_2$ calculations generally agree on a range of 3 to 8 'F (1.5 to 4.5 'C) as bounding the equilibrium warming responses given by a wide variety of current models.[47] The uncertainty in this benchmark warming is primarily due to uncertainty about feedbacks. The lower end of the range roughly corresponds to the direct impact of heat trapping associated with doubled $C0_2$, with little amplification from feedbacks. At the upper end of the range, feedback processes more than double the direct heat trapping effect. Some scientists believe that even more than an 8 'F warming could occur, due to hypothesized geochemical feedbacks that would release extra methane and $C0_2$ into the atmosphere, but which are not presently included in any models.[48]

It is important to realize that the3to8'F warming cited above only caps model predictions of warming in response to doubled $CO_2$; higher $CO_2$ concentrations or a combination of greenhouse gas levels equivalent to more than a doubling of $C0_2$ could lead to greater warming. U.S. EPA[49] has projected that in the absence of policies to slow emissions growth, an 'effective' $C0_2$ doubling (i.e., accounting for increases in other trace gases as well as ***$CO_2$)*** could occur as early as 2030, **assuming** high population and economic growth, or be delayed for about a decade, if low growth prevails. Beyond **that,** still higher trace gas concentrations and correspondingly more climate change would occur.

### *Reducing $CO_2$ Emissions in the Near-Term*

***$C0_2$*** is responsible for about 50 percent of current warming in this decade, with CFCs, methane, and nitrous oxide combined, contributing the other 50 percent (see figure 2-8). With anticipated controls on CFC emissions due to the Montreal Protocol, however, carbon dioxide's comparative contribution is expected to increase in the future. A recent EPA analysis (1989) suggests that to stabilize atmospheric concentrations of the greenhouse gases at current levels would require world-wide emission reductions from *today's levels* of 50 to *80* percent for $CO_2$, 10 to 20 percent for $CH_4$, 80 to 85 percent for $N_20$, and 75 to 100 percent for CFCs, and a freeze on carbon monoxide and $NO_X$. If the less developed countries are to grow in energy use at all, the developed world would have to virtually phase-out fossil fuels to achieve such a goal. In lieu of such a possibility, the world will continue to increase emissions of greenhouse gases and will most likely experience some warming over the next few decades.

The United States is responsible for about 21 percent of current greenhouse warming. In the United States, fossil fuel $C0_2$ emissions are distributed roughly equally across the industrial, transportation, and buildings sectors. (See figure *2-9.)* Per unit of energy produced, $C0_2$ emissions from coal combustion are highest, followed by oil and then natural gas. Oil and coal combustion each account for roughly 40 percent of U.S. emissions, with natural gas contributing the other 20 percent. The

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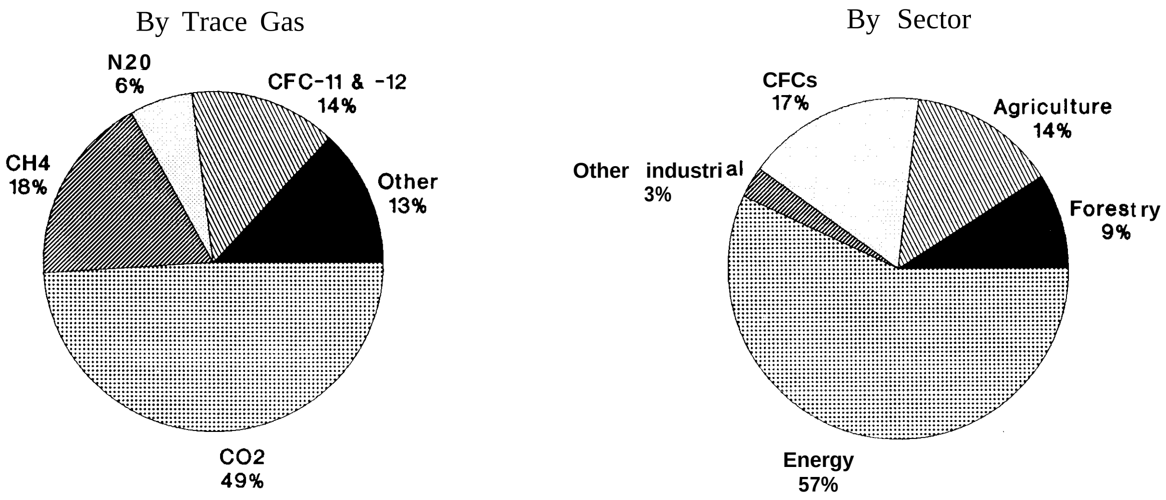
[47] National Academy of Sciences, Changing *Climate* (Washington DC: National Academy Press, 1983); and M.C. McCracken and F.M. Luther, *Projecting the Climatic Effects of Increasing Carbon Dioxide,* DOE/ER-0237, December 1985.

[48] Lashof, 1989, op. cit., footnote 40.

[49] U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, *Policy Options for Stabilizing Global Climate,* draft report to Congress, D.A. Lashof and D.A. Tirpak (eds.) (Washington, DC: February 1989).

**Figure 2-8-Current Contribution to Global Warming (percent)**



SOURCE: U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency[50] projects that annual world $CO_2$ emissions will increase from about 6 billion metric tons of carbon in 1985 to 9 to 12 billion metric tons of carbon in 2025, without new initiatives to reduce them. The U.S. contribution in 2025 is projected to be larger in absolute terms but smaller as a fraction of the world’s total than at present.

In 1988, at the now famous “Toronto Conference,’ scientists and policymakers from 47 countries called for a 20 percent reduction in carbon dioxide emissions from today’s levels by early in the next century. Several groups are attempting to calculate the potential for such reductions on a country by country basis[51]. Preliminary results suggest that substantial emissions reductions can be attained by efficiency improvements in all sectors of the economy (buildings, transportation, industry, energy supply, and agriculture). However, achieving a 20 percent reduction from current levels would not be possible by that time from efficiency changes alone. Pursuing such a goal would require changes in energy usage patterns and fuels consumed as well. These would probably require extensive government intervention to accomplish. In the transportation sector, VMT (vehicle miles traveled) are expected to grow at 2 to 3 percent per year, and efficiency improvements to grow at a slower rate (if current trends continue); thus, $CO_2$ emissions will continue to grow. Emissions are expected to increase about 25 percent between now and 2010 despite the appearance of new, more-efficient cars, trucks, and planes. To achieve a 20 percent reduction from 1987 levels in this sector therefore, would require both offsetting expected growth *and* decreasing emissions by an additional 20 percent.

## *The Transportation Sector and Global Warming*

Transportation’s impact on global warming comes principally from the $CO_2$ released by burning fuel. There are other contributions-refinery emissions and methane from tailpipes, for example-but these are much smaller than the warming contribution from $CO_2$.[52] Consequently, to a close approximation, studying transport’s contribution to global

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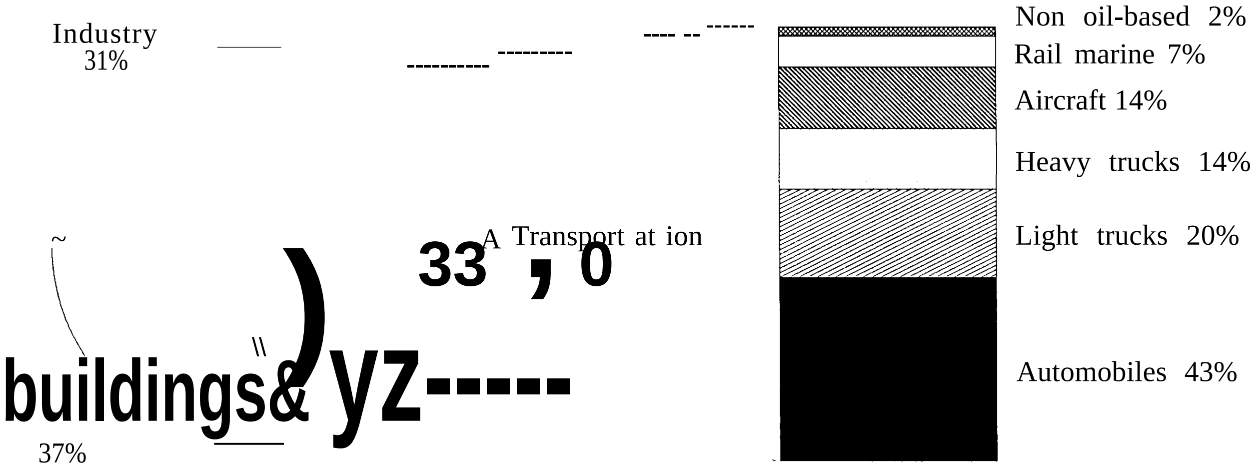
[50] U.S. Environmental Protection Agency, 1989, op. cit., footnote 49.

[51] Four U.S. studies are underway: by the U.S. Department of Energy, the U.S. Environmental Protection Agency, the Congressional Research Service, and the Office of Technology Assessment.

[52] If we consider U.S. highway vehicles, for example, DeLuchi et al. (M.A. DeLuchi, R.A. Johnston, and D. Sperling, “Transportation Fuels and the Greenhouse Effect,” UniversityWide Energy Research Group, University of California, UER-180, December 1987, p. 15) estimate the following shares of contribution to greenhouse emissions: 85 percent $CO_2$ from vehicle tailpipes, 11 percent $CO_2$ from production and nonhighway distribution of fuels, 3 percent from flaring and venting of natural gas, and 0.2 percent from tailpipe methane emissions.

**Figure 2-9-Contribution of the Transportation Sector to $CO_2$ Emissions**



Percent of total by sector
Total = 1.4 billion tons/year

Emissions from transportation, by category
Total . 0.46 billion tons/year

SOURCE: Oak Ridge National Laboratory.

warming is the same as studying transport energy consumption. The actual ‘‘ warming contribution,” expressed as mass of carbon emitted, is calculated by multiplying energy consumption by an emission coefficient that is roughly constant for all petroleum-based transport.

There are three important exceptions to this rough equivalence of greenhouse emissions and energy consumption, though. First, chlorofluorocarbons (CFCs), used in transport as air conditioning working fluids and, in smaller quantities, as foam padding and insulation, will not vary proportionally with energy consumption. Second, if other fuels replace petroleum as the principal source of transport energy, then the constant of proportionality between $CO_2$ emissions and energy use will change. Finally, the secondary effects of other tailpipe emissions such as carbon monoxide and reactive hydrocarbons may be large, for they both contribute to the formation of tropospheric ozone (also a greenhouse gas) and reduce concentrations of the hydroxyl radical (OH), which scavenges many trace gases from the atmosphere.

Short of capturing and storing the $CO_2$ produced by fossil fuel combustion-a remote possibility—the only way to reduce $CO_2$ emissions is to consume less fossil fuel. This can be accomplished by burning the fuel more efficiently (e.g., higher mpg cars), reducing demand for transportation services (driving less, carpooling), or actually changing fuels. Emissions of $CO_2$ per passenger mile depend on the kind of fuel efficiency technology in a car, but also on how big and powerful the car is, how fast it is driven, road and signal design, and how many people are in the car.

### *U.S. Transportation Energy Use and $CO_2$ Emissions*

The carbon emitted from the transport sector represents about 30 percent of total U.S. fossil fuel carbon emissions, and, as noted, the United States contributed 23 percent of world fossil fuel carbon emissions. Worldwide, fossil fuel combustion was about 75 to 80 percent of total carbon emissions (the rest came mostly from deforestation), and $CO_2$ represents about half of total current contributions to the greenhouse problem. Multiplying all these shares together indicates that the American transport sector contributes about 5 percent of total world $CO_2$ emissions, or about 2.5 percent of the total greenhouse problem. As figure 2 shows, the U.S. light-duty fleet-cars and light trucks-accounts for about 63 percent of U.S. transport emissions, or 3 percent of world $CO_2$ emissions, or 1.5 percent of the total greenhouse problem.

Future trends in transport greenhouse emissions will be determined by three factors: population growth, travel per person, and greenhouse emissions per unit of travel. Travel per person, and mode of travel, are determined by economic choices, many of which are constrained in the short run by existing patterns of settlement and available transportation infrastructure. Greenhouse emissions per unit of travel are largely determined by vehicle efficiency technology, including such market-determined factors as the average size and power of vehicles in the fleet. These factors are also constrained in the short run, due to the remaining lifetime of existing vehicles and the lead times required for introduction of substantial innovations in new vehicles.

Cars and light trucks are likely to continue to dominate U.S. transport. Consequently, the single most important factor determining future transport energy use and greenhouse emissions will be the rate of light vehicle efficiency gains. Although today's best production models and prototypes, surpass 50 mpg and 80 mpg respectively, fleet increases in efficiency to this level are unlikely. Consumer preference for larger and more powerful vehicles suggest that, under current conditions, efficiencies this high cannot be translated into production fleet performance.

### Alternative Fuels

***New*** transport fuels may also change the rate of greenhouse emissions per unit of travel. Fuels under development include methanol derived from natural gas or coal, ethanol derived from fermented plant feedstocks, natural gas in compressed (CNG) or liquefied (LNG) form, and hydrogen derived from electrolysis of water. Electric vehicles that run on rechargeable batteries are also being developed aggressively. To assess the greenhouse effects of new fuels, you must look beyond the tailpipe. In the present petroleum-based system, emissions of $CO_2$ from vehicles represent about 85 percent of total transport-associated greenhouse emissions; the other 15 percent comes from the production, refining, and transmission of the fuel, and venting and flaring of natural gas found with the petroleum. Changes in vehicle efficiency or travel patterns alone, without changes in the sources of transport fuel, will keep this relationship unchanged; if $CO_2$ from vehicles declined by 25 percent, greenhouse emissions from the transport system would decline by 25 percent. But new fuels will change the relationship, because their sources and manufacture will be different. Consequently, it is necessary to add up total greenhouse emissions from extraction, production, distribution, and use of new fuels to assess their net impact on emissions.

While other fuels could reduce greenhouse emissions, large movement to new transport fuels is blocked by two categories of obstacles: technical problems of cost, vehicle performance and fuel storage; and threshold problems related to fuel distribution and repair systems. The new power sources that offer the largest reductions in greenhouse emissions-hydrogen or electricity from nonfossil sources-are the furthest from large-scale technical viability, and the most difficult to move to from a gasoline system.

As discussed in the chapters that follow, although there are serious disagreements about details, there is a substantial consensus that those alternative fuels that are most ready for the marketplace will *not* substantially alter the effective volume of greenhouse gases produced by the transportation sector—assuming that feedstocks are selected based on market prices rather than national security considerations or global warming considerations (so that natural gas is likely to be the primary feedstock, rather than coal or biomass). This conclusion is reached not only because no new fuel, except possibly reformulated gasoline, will penetrate deeply into the marketplace by the end of this century, but also because the fuels most likely to *begin* to penetrate don't offer a substantial advantage over gasoline in their net greenhouse emissions.

*Methanol and compressed or liquefied natural gas will* rely, at least at first, on geologic deposits of natural gas as their primary feedstock. Although methane, the key constituent of natural gas, generates less $CO_2$ per unit of energy on combustion than does gasoline, methane is itself a potent greenhouse gas and will be a major component of the emissions from natural gas-fueled vehicles. This, coupled with certain energy inefficiencies in transporting and/or transforming the natural gas, approximately compensate for methane's advantage in combustion $CO_2$ emissions. *Reformulated gasoline* may gain or lose greenhouse emissions "advantages" by adding or subtracting various components of gasoline, but the net effect is highly uncertain (because the actual makeup of reformulated gasoline is highly uncertain) and unlikely to be large. We would guess that reformulated gasoline will create a small net increase in greenhouse emissions. And *ethanol is* theoretically attractive because its primary feedstocks, sugar and starch crops, are renewable, with plant growth reabsorbing the $CO_2$ lost to combustion. However, with current agricultural and fuel production technology, the energy used to grow the feedstocks and convert them to ethanol produces enough $CO_2$ to roughly negate the advantage gained by crop regrowth; without changes in the production system, ethanol use will generate about as much $CO_2$ as gasoline use.

*Electricity and hydrogen are* often cited as fuels that could yield substantially reduced greenhouse emissions. However, these reductions can be achieved only by using energy feedstocks—probably nuclear in the case of electricity, solar for hydrogen-that at present are either not available in large quantities or not economic. Both of these "fuels" probably are longer term alternatives, not likely to be the fuel of choice for any program seeking to put millions of vehicles on the road before the year 2000.

If the near-term options will not greatly affect greenhouse emissions, should we then *not* consider global warming implications in making decisions about promoting alternative fuels? Environmentalists are making the following arguments *for the* proposition that decisions about alternative fuels are a key factor in global warming strategies:

- *Some decisions about alternative fuels will foreclose future options.* Introducing particular alternative fuels may open or foreclose future fuel options that *do* have profound greenhouse implications. For example, introducing natural gas as an alternative may open the way for future use of hydrogen, by making gaseous fuels more familiar and by developing a gas-oriented infrastructure that is more convertible to hydrogen use than would be an infrastructure based on liquids. Alternatively, introducing new liquid fuels may make it far more difficult to switch to hydrogen later on, given the large investment made in new, liquids-oriented infrastructure.

  As a corollary to the above argument, introducing any new fuel using fossil materials, e.g., natural gas, will simply prolong the age of fossil-based transportation fuels and delay entry of renewable fuels. To fight global warming, we must begin to make a transition from fossil fuels as soon as possible. Moving from one fossil fuel (petroleum) to another (natural gas) is basically defeatist. We should instead move as quickly as possible to solar or biomass-based fuels.

- *Introduction of some fuels will lead inexorably to more coal use.* Introducing fuels that are dependent on fossil materials as feedstocks will inevitably lead to a dependence on coal as the feedstock. Such a dependence will have a profound greenhouse impact, so that consideration of the long-term feedstock sources for the alternative fuels must take place before setting us on a particular path.
- *Current estimates of greenhouse emissions don't consider future technology improvements.* The fact that several of the alternative fuels can *match* gasoline in greenhouse emissions should be viewed as encouraging rather than disappointing, given the current rudimentary state-of-the-art of much of the fuel cycle for the various alternatives. It is inevitable that commercial development of these fuels will stimulate substantial improvements to efficiency in production and utilization, and consequent reductions in greenhouse emissions. Although the current gasoline-based system can improve as well, it has less opportunity because of its maturity.

OTA agrees with some of these concerns, with caveats. We do believe that the near-term fuel choices will affect the potential for introducing other fuels in the future; we do not believe that these effects are necessarily very straightforward, however (as in the argument that introduction of near-term gaseous fuels will assist longer term hydrogen fuel development), nor necessarily so predictable that this concern should play a key role in selecting fuels. We agree that moving to methanol or natural gas will increase the chances of our eventually moving to coal as a transportation feedstock, and may even prolong our use of fossil transportation fuels, but *only* because these fuels are in some ways more attractive than gasoline and may make a fossil-based system more congenial. If we ran out of oil and had not turned to methanol or natural gas, this would *not* necessarily push us towards renewable, however; like methanol and natural gas, gasoline can also be made from coal (or natural gas).

Finally, we agree that technology improvements will improve the future net greenhouse balance of the alternative fuels, although resource depletion might eventually work in the other direction.

In the chapters on the individual fuels that follow, we have relied in large measure on the analyses of fuel cycle greenhouse emissions conducted by Mark DeLuchi, Daniel Sperling, and colleagues at the University of California at Davis. These analyses are comprehensive and superbly documented.